International Monorail Association

Performance Specification for a Turnkey Mass Transit Monorail System

Edition 1.1, June 2026

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INTERNATIONAL MONORAIL ASSOCIATION

Foreword

Faced with an escalating demand for public transportation in metropolitan areas, transportation authorities are challenged to select a technology that will satisfy the often-conflicting demands of high capacity and reliable service, urban fit, minimized environmental impact and budget restrictions. In order to further promote the use of monorails, there is a particular need for a tool which enables the evaluation of monorails in comparison to other transport systems in the course of higher-level transport planning or concrete tenders.

With the "Turnkey System Performance Specification for Mass Transit Monorail", the International Monorail Association has developed just such a performance catalogue for components, subsystems, vehicles, and the infrastructure. It describes the performance of an entire monorail system in a way which enables users to understand what is possible and what can be requested. It also gives the vehicle and infrastructure supply industry a better insight into technology requirements and avoids system-specific isolated solutions. This performance-oriented standardisation will ensure more competition along the supply chain and further strengthen the economic efficiency of the overall system.

This document contains the first revision to the first edition of the service catalog focusing on improvements of the passenger safety sections. Many Experts from around the world and from various disciplines - for example, from vehicle technology, control and safety technology, infrastructure, civil and structural engineering, or very specific subsystems and components - began working on the initial foundations for performance-based standardization back in 2014. Then, in 2019, a comprehensive review process began with the participation of additional experts and operators and concluded with commentary at the IMA's Monorailex 2021 industry meeting in Milan, Italy. And now, in 2026, thanks to the collaboration of many monorail experts we bring revision 1.1, containing updates to emergency walkways based on risk analysis looking at this issue from a system wide approach.

The Executive Board Members of the International Monorail Association would like to thank all the volunteer professionals around the globe for their exceptionally successful work.

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The "Turnkey System Performance Specification for Mass Transit Monorail – Edition 1.1" is an important pillar for further establishment of monorails as an efficient reliable, safe, environmentally friendly public transport solution.

It is the intention of the IMA to carry on development of this Performance Specification through active committee work as new insights, new standards and revisions are foreseen. Active participation of the international monorail community is encouraged.

The IMA Executive Council, June 2026

Disclaimer

International Monorail Association (IMA)

Performance Specification for a Turnkey Mass Transit Monorail System, Edition 1.1

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Revision Log

Revision	Date (yyyy-mm-dd)	Description of Changes
0	2015-11-05	First issue
1	2016-03-11	Updated
2	2022-09-15	Update by IMA experts and publication
3	*2026-04-03*	*Revision and update on Passenger Safety* - *Revision of chapter 7 introduction* - *Revision of chapter 7.1* - *New chapter 7.3.3* - *New appendix 3: Guidelines for Rescue and Evacuation of Passengers* *New release of the whole document as 'Edition 1.1'*

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1 Introduction

History demonstrates that the most suitable and cost-effective automated transit systems are procured as turnkey systems, following a System Performance Specification rather than a more prescriptive approach. Automated metro, Monorail and APM project implementation is most timely and economical when:

- The contract is structured so that there is a single point of responsibility (turnkey system not multi-contract approach)
- The contract includes a substantial period of operations and maintenance as well as system design / build (such as in a DBOM or BOT approach)
- The contract is based on a System Performance Specification rather than detailed presciptive specifications
- The procurement requires proven system technology and GoA 4 operating experience.

Turnkey System procurement with performance-based technical specifications permits potential monorail system suppliers to offer an overall optimised solution that is tailored to best meet a Client's System operating requirements. The inclusion of an extended term of operation and maintenance as part of the initial performance-based turnkey design / build contract results in the best-integrated System as well as the lowest overall life cycle cost.

This System Performance Specification presents System design, build, operations and maintenance requirements for a hypothetical mass transit-grade, GoA 4 (driverless and unattended, UTO) straddle monorail System. The intention is that a client (or consultant defined as client) would replace hypothetical parameters (as noted) with the parameters appropriate for the desired System and use the resulting Specification as a basis for an Invitation to Tender.

A turnkey System Contractor (the Contractor) shall provide all the functionality required by this specification) and is the single point of responsibility for the successful completion of these activities. The Contractor shall choose how to provide this functionality including which subsystems or components are responsible to provide functionality.

2 Abbreviations, Definitions, and Standards

2.1 Abbreviations and Definitions

The abbreviations and definitions used in this Performance Specification are defined in Table 2-1, below.

Table 2-1 Abbreviations and Definitions

Abbreviations	Definition
A&E	Architectural and Engineering
AARU	Automatic Assured Receptivity Unit
AC	Alternating current
ADA	Americans with Disabilities Act
AFC	Automatic Fare Collection
ALARP	As Low As Reasonably Practicable
ANSI	American National Standards Institute
APM	Automated People Mover
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigeration and Air Conditioning Engineers
ATC	Automatic Train Control
ATP	Automatic Train Protection
ATO	Automatic Train Operations
ATR	Automatic Train Regulation
ATS	Automatic Train Supervision
AW0, AW1, AW2, AW3, AW4	Vehicle design weights as defined in Section 9
BOT	Build-Operate-Transfer
BTU	Basic Train Unit
CBTC	Communications Based Train Control
CCC	Central Control Console
CCD	Charge Coupled Device
CCF	Central Control Facility
CCO	Central Control Operator
CCTV	Closed Circuit Television
CENELEC	European Committee For Electrotechnical Standardization (Commission Européenne de Normalisation Électrique)

Abbreviations	Definition
CLS	Closed and Locked Status
CRC	Cyclic Redundancy Check
CSC	Contactless Smart Card
CSD	Combined Service Drawing
CTS	Communications Transmission Subsystem
D(FA)	Declarable for Assessment
D(FI)	Declarable for Information
DB	Design Build
DBOM	Design-Build-Operate-Maintain
DC	Direct Current
DCIM	Design/Construction Interface Manual
DCS	Door Closed Status
DDOT	Dwell Door Open Time
EB	Emergency Brake
E&M	Electrical and Mechanical
EMC	Electromagnetic Compatibility
EMI	Electromagnetic Interference
EMU	Electric Multiple Unit
FAI	First Article Inspection
FAS	Fire Alarm System
FDR	Final Design Review
FES	Fire Extinguishing System
FMEA	Failure Mode and Effects Analysis
FMECA	Failure Mode, Effects & Criticality Analysis
FSS	Fire Suppression System
FTA	Fault Tree Analysis
GoA	Grade of Automation (from the International Association of Public Transport, UITP)
HVAC	Heating, Ventilation & Air Conditioning
ICD	Interface Control Document
IEEE	Institute of Electrical and Electronics Engineers
IEC	International Electrotechnical Commission
IP	Inspection Plan

Abbreviations	Definition
ISO	International Standards Organization
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LO	Locked Out
LOS	Level of Service
LPM	Litres per Minute
LRU	Line Replaceable Unit
MDBF	Mean Distance Between Failures
MI&H	Mobility-Impaired and Handicapped
MMI	Man-Machine Interface
MMIS	Maintenance Management Information System
MSTP	Multiple Spanning Tree Protocol
MTBF	Mean Time Between Failures
MTBSAF	Mean Time Between Service-Affecting Failures
MRV	Maintenance and Recovery Vehicle
MTTRs	Mean-Time-to-Restore
MTTR	Mean-Time-to-Repair
NFPA	National Fire Protection Association (USA)
NMS	Network Management Subsystem
NTP	Notice to Proceed
O&M	Operations and Maintenance
OBCU	On Board Control Unit
OISA	Overall Independent System Assessor
OMSF	Operations, Maintenance and Storage Facility
OSHA	Occupational Safety and Health Administration
OVLD	Over-Voltage Limiting Device
PA	Public Address
PABX	Private Automated Branch Exchange
P(AR)	Prohibited in Area of Restriction
PDC	Platform Door Controller
PDR	Preliminary Design Review
PI	Passenger Information
PICO	Post-Installation Check-Out

Abbreviations	Definition
PID	Passenger Information Display
PIN	Personal Identification Number
PM	Preventive Maintenance
PPH	People per hour
PPHPD	People (transit system riders) per hour per direction
PSDS	Platform Screen Door Subsystem
PS&D	Power Supply and Distribution
PSTN	Public Switched Telephone Network
QA/QC	Quality Assurance / Quality Control
RAM	Reliability, Availability, and Maintainability
RF	Radio Frequency
RMM	Recovery Manual Mode
RMS	Root Mean Square
RTU	Remote Terminal Unit
SCADA	Supervisory Control And Data Acquisition
SAE	Society of Automotive Engineers
SAF	Service Affecting Failure
SDH	System Design Headway
SDR	System Design Review
SDRT	Station Dwell Reaction Time
SDT	Station Dwell Time
SI	International System of Units, Système international d'unités
SOFRP	System Operating and Fault Recovery Plan
SPFMA	System Performance and Failure Management Analysis
SPS	System Performance Specification
SRL	Safety Requirement Level
SSD	System Schematic Display
SSD	System Status Display
THR	Tolerable Hazard Rate
TOH	Train Operating Hours
TOM	Ticket Office Machine
TPS	Traction Power Substation
TTR	Time to Restore

Abbreviations	Definition
TVM	Ticket Vending Machine
UITP	International Union of Public Transport
UNIFE	European Rail Industry Association
UPS	Uninterruptible Power Supply
UTO	Unattended Train Operation
VDU	Visual Display Unit
VTA	Verification, Test and Acceptance

The following definitions apply throughout this System Performance Specification:

Table 2-2 Terms and Definitions

Term	Definition
Adhesion, Coefficient of	During rolling contact, the ratio between the attainable longitudinal tangential force at the wheel-running surface interface and normal force.
Alteration	A change or substitution in the form, character, or detail of the work done or to be done within the original scope of the Contract.
Approval	Acceptance in writing by the Client, Client’s Oversight Consultant, or another authority, as applicable.
Approved or Approved Type	Design type material, procedure, or method given approval by the Client, or another authority, as applicable.
Availability	The probability that a given system is operational or ready to be placed in service.
Bogie	A vehicle undercarriage assembly containing wheels and axles, motors, gearboxes, brakes, collectors, cable, piping, etc. Also called a truck.
Car	The smallest passenger carrying unit, perhaps a vehicle of itself, but generally coupled together to make vehicles and consists, and trains.
Central Control Console	The Central Control Operators' workstation(s) within the Central Control Facility, consisting of displays and controls that permit all necessary interfaces with the ATC and communications subsystems.

Term	Definition
Central Control Facility (CCF)	A room within the OMSF in which the Central Control Operators perform their tasks and duties and in which are located the System Schematic Display, the Power Schematic Display, the General System Display, the CCC, and related ATC, communications, and SCADA equipment.
Central Control Operator (CCO)	Any operations staff member whose work area is the CCF and who uses ATC equipment and other communication, control, audio, and visual equipment to interact with the System to maintain System performance. CCO can refer to one or more such persons when describing actions or capabilities.
Client	The entity legally, practically, and financially enabled to enter to a contract with the Contractor for delivery of the System described by this System Performance Specification.
Comfort Speed	The speed of travel through a constant-radius curve at which the Lateral component of centripetal acceleration is equally balanced by gravity due to Superelevation.
Commercial Speed	Commercial Speed shall have the meaning as defined in Section 5.1.4 of this System Requirement Specification.
Consist	The configuration of the cars and vehicles operating as a train.
Contractor	The entity contracted by the Client to deliver the system that meets the requirements of this system requirement specification.
Days	Unless otherwise designated, days will be understood to mean calendar days.
Days, Working	Those Days during which regular business is conducted, therefor excluding days of rest and all statutory holidays in the locale.
Design Load	All applicable loads and forces or their related internal moments and forces used to proportion members.

Term	Definition
Downtime Event	One or more System-related problems that cause unscheduled stoppage or delay of one or more vehicles on any portion of the track for a period as defined in section 8.1. Inability to dispatch from a station is also considered an unscheduled stoppage. The problem may be hardware or software failure or may be a random stoppage not traceable to a specific cause. Stoppages resulting from causes listed as Exclusions shall not be counted as downtime events.
Downtime	The accumulated time of all downtime events. Downtime for an event shall include all time from when vehicle movement was interrupted until the fault was cleared and the first vehicle blocked by the failure has resumed movement for passenger services.
Drive	A system consisting of one or several motors or actuators, their direct control equipment (power circuits), and the associated mechanical devices required to produce a useful output.
Dwell	Dwell time is defined as Station Dwell Time.
Dwell Door Open Time	Dwell Door Open Time shall have the meaning as defined in Section 5.1.3 of this Specification.
Exclusions	System Availability events that are not considered Downtime Events, as listed in Section 8.1. Delays due to these Exclusions will not be used in evaluating System availability
Fail-safe	A system element designed such that, in the occurrence of a failure, the system remains safe.
Failure	An inability to perform an intended function, but excluding the following: • A consumable item. • A dependent failure. • Collision, accident, vandalism, or negligence of the operator. • Incorrect or abusive use by the operation or maintenance personnel or by incorrect operation or maintenance procedures or practices by the operator. • A preventive maintenance action. • Passenger-induced failure.

Term	Definition
Failure Rate	The frequency of failure, expressed as failures per hour or failures per mile. Failure rate is the mathematical reciprocal of mean time between failures (MTBF) or mean distance between failures (MDBF).
First Article	The first item of production that fixes and defines all subsequent production items.
Finish-out	All construction work in addition to the basic structure and shell to finish a building or space so that it requires no additional work prior to use for its intended purpose, other than installation of specific Contractor-supplied equipment.
Fixed Facilities	Fixed Facilities shall have the meaning as defined in Section 3.3 of this Specification.
FMEA	Failure modes and effects analysis
Guide Beam	One of the component beams of the guideway upon which the monorail vehicles are guided and supported. Includes the running and guidance surfaces.
Guideway	Denotes the structure upon which the monorail vehicles are guided and supported, and path of that structure through the System. Analogous to the steel tracks of steel-wheel, steel-rail transit systems.
Headway	Headway shall have the meaning as defined in Section 5.1.2 of this Specification. Essentially and for reference only, the elapsed time between two consecutive trains traveling in the same direction on the same track.
Headway, Operational	Operational Headway, or Service Interval, shall have the meaning as defined in Section 5.1.2 of this Specification. Essentially and for reference only, the planned (scheduled) Headway. The Operational Headway can be maintained reliably when there are no failures or external perturbations.
Headway, Non-interference	See System Design Headway
Headway, System Design	System Design Headway, or Non-interference Headway, shall have the meaning as defined in Section 5.1.2 of this Specification. Essentially and for reference only, the minimum headway at which trains can circulate throughout the System without having to stop or reduce speed due to trains ahead.
Hot Berthing	When a train is waiting to depart when another train arrives at a station.

Term	Definition
Inspection	The checking or testing for condition, performance, and safety of equipment against established standards.
Interface	The points where two or more functional systems, subsystems, or structures come into physical or functional contact.
Jerk	Time rate of change of acceleration and deceleration, equal to the second derivative of velocity with respect to time.
Lateral	Side to side in a vehicle, the y direction in ISO 2631-2010.
Line Replaceable Unit (LRU)	Assembly designed for replacement from a vehicle or wayside installation (first level maintenance) in order to return the vehicle or wayside equipment to a serviceable state.
Lowest Level Replaceable Unit (LLRU)	The smallest unit for line replacement, such as a component, circuit board, or assembly, that would be replaced in effecting a repair of the system or subsystem in accordance with the Contractor's specific maintenance plan.
Longitudinal	Fore and aft in a vehicle, the x direction in ISO 2631-2010
Mainline	That portion of the guideway that is used to transport passengers in service, that is, not part of the OMSF, lines leading to it that do not carry passengers, or vehicle / train storage tracks.
Maintenance and Recovery Vehicle (MRV)	Any vehicle capable of being guideway-mounted, designed to maintain the guideway and guideway -mounted equipment, carry system equipment along the track for use in subsystem maintenance and repair, and possibly to retrieve failed passenger vehicles/trains from the track. The guideway design shall include consideration of the weights associated with the recovery vehicle operation.
Maintenance Management Information System	An automated system capable of providing the system departmental manager and staff with operational data required for analysis and determination of system performance and efficiency. Capable of collection, processing, storage, retrieval, analysis and reporting of reliability, efficiency and effectiveness-related information pertaining to all aspects of the system.

Term	Definition
Maintenance Planning System	An automated system of cost, work, and manpower planning, scheduling, and control, either manual or automated, generally part of a total maintenance management information system.
Manufacturer	The builder or producer supplying materials, equipment, or apparatus for installation.
Maximum Load Point (Peak Link)	The link between adjacent stations with the heaviest passenger load by direction, expressed as passengers per hour per direction.
Mean Distance Between Failures (MDBF)	The mean operating mileage between failures.
Mean Time Between Failures (MTBF)	The mean operating time between failures.
Mean Time to Restore (MTTRs)	The average time required to diagnose, repair, or replace and ascertain that a unit of equipment of the system is ready to go back into service following its malfunction, and restart that unit on the system to service. The MTTR does not include mobilization time and time to obtain the required items from stores.
Mobility Impaired and Handicapped (MI&H)	Riders who have mobility-related limitations. Often referred to as “elderly” and “handicapped” in transportation literature.
No Motion	The car speed at or below the lowest speed reliably detectable by the car sensors.
Normal	A condition in which relevant car equipment is not in a failure mode and the environment is as specified.
Notice to Proceed (NTP)	The written directive from Client to Contractor authorizing the Contractor to begin the execution of work as specified in the Contract Documents of which this Performance Specification is part thereof.
O&M Contractor	Shall have the meaning set forth in Introduction.
Operating Hours	The scheduled and actual number of hours during which the System provides service in an operating period.
Operating Modes	The normal, contingent, and other operations of the System.

Term	Definition
Operating Schedule	The specific scheme of vehicle/train operations scheduled on an hourly, daily, and weekly basis, in accordance with this System Performance Specification.
Operations, Maintenance and Storage Facility (OMSF)	An area encompassing the CCF, a maintenance facility with repair shops, work bays, maintenance vehicles and related amenities, a vehicle storage area, and administrative offices related to and necessary in connection with System operation and such facilities.
Overtravel Buffer	A device placed at any track terminus to provide a controlled deceleration should a train not stop before reaching the device.
Part	Component.
Peak Period	The time interval of greatest system patronage demand.
Proof (used as a suffix)	The device and contents are impervious to, or unharmed by the indicated materials, environment, or other outside elements, as in splash proof or dust proof.
Proven Design	As used here, a proven design is defined as those technologies of that have been successfully deployed in day-to-day service in other monorail or mass-transit systems.
Provide	Design, construct, furnish / install or complete in place, and test.
Redundancy	A design approach in which more than one unit that can meet the required functionality is implemented. Redundancy has one of two objectives, to enable a function to be performed in the event of the failure of one unit, or to enable failure to be detected by comparing the outputs of two units. The second purpose is called “checked redundant” and enables a system to revert to a safe state in the event of failure.
Reference Drawings	The drawings that generally describe the location and design of the System, its facilities, and its other elements and ancillary structures.
Reliability	The probability that a system, subsystem, component, or part will perform satisfactorily when used under stated conditions for a stated period of time.

Term	Definition
Right-of-Way	The easements, land, and path reserved for the system guideway, associated wayside equipment, and access thereto. The OMSF may not be included in the Right-of-Way.
Safety	Freedom from unacceptable risk.
Safety Critical	A system element or function, which is required to assure safe system operation.
Scheduled Service	Periods when the system is functioning to transport passengers in accordance with the Operations Plan, including time sequence of vehicle arrivals and departures resulting from planned number of vehicles following their planned routings.
Service	The operation of the system with passengers.
Service Interval	See Operational Headway
Shop	Any facility designed for maintenance activities.
Specification	This System Performance Specification.
Station Dwell Reaction Time	Station Dwell Reaction Time shall have the meaning as defined in Section 5.1.3 of this Specification.
Station Dwell Time	Station Dwell Time shall have the meaning as defined in Section 5.1.3 of this Specification.
Stop, Emergency	The stopping of a vehicle or train by an emergency brake application.
Stop, Service	The stopping of a vehicle or train by application of the service brakes.
Storage Track	A section of guideway used to store service-ready vehicles / trains prior to their dispatch into Service and trains removed from Service. Storage tracks generally are in the automated part of the system and are located in the yard of the OMSF and where applicable at terminal stations and strategically along the mainline as required to meet availability and operational requirements.
Substation (Traction Power)	A facility in which electrical power is received and converted to DC voltage of a lower level for distribution on the guideway.

Term	Definition
Superelevation	The angle of the top running surface of the guideway with respect to local horizontal (perpendicular to gravity).
Sustained	Durations equal to or greater than 2 seconds.
System	The transit system specified by this System Performance Specification, including the fleet, guideway, civil infrastructure, wayside infrastructure, power distribution, signalling, track equipment, and all other elements supplied by the Contractor.
System Equipment	The vehicles, switches, emergency walkway, traction power and back-up power equipment, OMSF equipment, ATC and other signalling equipment, communications equipment, signage, safety and security equipment, station platform equipment, maintenance tools and equipment, and all other equipment required by the System.
System Technology	System Technology shall have the meaning as defined in Section 3.2 of this Specification.
Track	Herein denotes the guideway and guide beams in analogy with the steel tracks of steel-wheel, steel-rail transit systems. Includes the running and guidance surfaces.
Traction System	The system of wheels, motors, gears, brakes, direct controls, and appurtenances that propels or retards a vehicle in response to control signals.
Train	A set of two or more cars coupled together and operated as a single unit, displaying a headlight to the front and taillight to the rear. Trains or vehicles may be coupled to form a larger train.
Truck	A vehicle undercarriage assembly containing wheels and axles, motors, gearboxes, brakes, collectors, cable, piping, etc. Also called a bogie.
Validation	The process of demonstrating that a system, subsystem, function, or component generally does as expect and produces a result that is suitable for the application.
Verification	The process of proving that a system, subsystem, function, or component will consistently do as expected to produce a result that will consistently satisfy a pre-determined requirement.

Term	Definition
Vertical	Up and down, the z direction in ISO 2631-2010
Vehicle	An autonomous passenger carrying unit intended for passenger service with multiple cars (if any) semi-permanently coupled.
Vital	A term applied to a device or circuit which has known failure modes, certain of which occur with extreme rarity.
Vital Component or Circuit	Any device, circuit, or software module used to implement a Vital function.
Wayside	The geographic portion of the system along the guideway and within the Right-of-Way, also an adverb attached to the equipment therein or associated with it (usually to distinguish it from vehicle-borne equipment).

2.2 Codes, Regulations and Standards

The System shall be designed, constructed, operated, and maintained in accordance with local and internationally recognized codes, regulations, and standards. A list of the common international standards relevant to straddle-beam monorails is given in Appendix 1: International Standards for Straddle-Beam Monorails. Equivalent internationally recognized standards may be substituted. Local standards shall be used to substitute or supplement, especially as required by law.

The System shall be designed generally following IEC and CENELEC standards, and the ASCE 21 Automated People Movers standard where this standard does not conflict.

The System shall also comply with the American standard NFPA 130 for fire protection. Compliance to the CENELEC EN 45545 railway vehicle fire protection standard may substitute where appropriate.

Design, manufacture, supply, and verification of the System (including the fleet) shall follow CENELEC standard EN50126 “The specification and demonstration of Reliability, Availability, Maintainability and Safety”.

2.3 Prohibited and Declarable Substances

Substances classified as “Prohibited in Area of Restriction, P(AR)” in the UNIFE (Railway Industry Association) Railway Industry Substance List shall not be present in finished goods, parts or components defined in the “area of restriction” for this System.

Substances classified as “Declarable for Assessment, D(FA)” in the UNIFE list shall be declared to the Client and delivered subject to Client approval.

Substances classified as “Declarable for Information, D(FI)” in the UNIFE list shall be declared to the Client.

3 System Description

3.1 System Overview

The Project consists of the turnkey design, supply, installation, test, and commissioning of the System followed by defined period for the operation and maintenance of the System for a period of five years, renewable at option of Client.

The System consists of a service-proven, transit-grade, automated and unattended (UTO), GoA 4 straddle-beam monorail system comprising System Technology and Fixed Facilities scope as outlined below.

System Technology consists of:

- Rolling Stock
- Power Supply and Distribution (PS&D)
- Automatic Train Control (ATC)
- Communications subsystem
- Supervisory Control and Data Acquisition (SCADA)
- Central Control Facility (CCF) equipment
- Automatic Fare Collection (AFC)
- Guideway equipment including switch equipment
- Station equipment including Platform Screen Door Subsystem (PSDS)
- Operations, Maintenance and Storage Facility (OMSF) equipment
- Corrosion control, grounding, lightning and other protection
- Systems activities.

These System Technology scope items are further outlined in System Technology below.

Fixed Facilities scope consists of:

- Guideway
- Passenger stations
- Operations, Maintenance and Storage Facility (OMSF)
- Auxiliary buildings.

These Fixed Facility scope items are further outlined in Fixed Facilities below.

Operations and Maintenance scope consists of:

- System Operations
- System Maintenance
- O&M Documentation
- O&M Manuals
- O&M Training.

These O&M scope items are further outlined in System Operations and Maintenance below.

3.2 System Technology

The first level of the System Technology scope is shown in Section 3.1 above. The following is a guide to locating detailed requirements in this document.

Passenger vehicle requirements can be found in Section 9.

Power Supply and Distribution (PS&D) provides power to the trains from traction substations through power rails and power collectors on the vehicles or equivalent as required by the technology. It also provides housekeeping power to passenger stations, the OMSF and CCF as well as back-up power throughout the System. PS&D requirements can be found in Section 10.

Automatic Train Control (ATC) provides Automatic Train Protection (ATP), Automatic Train Operations (ATO) and Automatic Train Supervision (ATS). ATC requirements can be found in Section 11.

Communications subsystems include the fibre optic backbone, radios and telephones, on-board and wayside video surveillance, public address, passenger audio communications, passenger information displays, video, and voice recording. Communications requirements can be found in Section 12 below.

Supervisory Control and Data Acquisition (SCADA) requirements can be found in Section 13 below.

Central Control Facility (CCF) equipment requirements can be found in Section 14 below.

Automatic Fare Collection (AFC) includes ticket vending machines, ticket office machines, fare gates, station or digital systems for fare collection and central computer systems. AFC requirements can be found in Section 15 below.

Guideway equipment includes switches, end-of-line overtravel buffers, and wayside equipment such as cable trays, emergency walkways, lighting, and signage. Guideway equipment requirements can be found in Section 170 below.

Station equipment includes Platform Passenger Protection System e. g. the Platform Screen Door Subsystem (PSDS), elevator and escalator equipment, connections to emergency walkways, lighting, HVAC, plumbing, communications, and miscellaneous electrical and mechanical equipment. Station equipment requirements can be found in Section 18 below.

Operations, Maintenance and Storage Facility (OMSF) and equipment provides for automated train storage and dispatch, train wash facility, vehicle and wayside equipment maintenance and repair, workshops, tools, test equipment, Maintenance Management Information System (MMIS) maintenance and retrieval vehicles, spare parts, consumables, facilities for employees, supervision area and offices. OMSF requirements can be found in Section 19 below.

Corrosion control and grounding requirements can be found in Section 22 below.

Systems activities include systems engineering and integration, system environmental design, System safety and security, System dependability, Systems assurance and verification, and System documentation. Requirements related to these activities can be found in Sections 4, 6, 7, 8, 23 and 26 below.

Introduction of new Technologies

Where new technologies are to be introduced, the Contractor shall ensure that the validation program provides appropriate testing and validation methods to demonstrate suitability and compliance to the reliability, availability, maintainability, and safety requirements.

3.3 Fixed Facilities

The first-level breakout of the Fixed Facilities scope is shown in Section 3.1 above.

Guideway scope includes foundations, columns and other support structure, guideway beams for tangent, curved and transition guideways, and switch support structures on the mainline guideway and in the OMSF. Guideway requirements can be found in Sections 16, 17, 20 and 21 below.

Passenger station scope includes foundations, columns and other support structure and the station structure itself together with building services, furniture, and equipment. Passenger station requirements can be found in Sections 18, 20 and 21 below.

OMSF scope includes foundations for OMSF buildings, and the building structures themselves together with building services, furniture, and equipment. OMSF requirements can be found in Sections 19, 20 and 21.

Auxiliary buildings may include the Central Control Facility (CCF), administrative offices, traction, and auxiliary power substations to the degree that they are not included in the passenger stations or the main OMSF building. Auxiliary building scope includes foundations, and the building structures themselves together with building services, furniture, and equipment. Requirements can be found in Sections 20 and 21.

3.4 System Operations and Maintenance

The first-level breakout of the System Operations and Maintenance scope is shown in Section 3.1. In this breakout:

- System Operations includes operating characteristics, normal, degraded-mode and emergency operating modes, System start-up and shutdown, failure management, and System operations plans (see Sections 5.1 – 5.4 and 24.1)
- System Maintenance includes the System maintenance plan, OMSF, maintenance tools and equipment and the Maintenance Management Information System (MMIS) (see Sections 5.5, 19 and 24.1)
- O&M Documentation includes System operations and maintenance plans, standard operating procedures, lists for spare parts and special tools and equipment, training plans, O&M manuals and operating rule book (see Sections 26.1, 26.2, 26.4 and 24.2).
- O&M Manuals include preliminary, updated and final copies for all subsystems, equipment and software and illustrated parts catalogues (see Sections 26.4 and 24.2)
- Training includes the preparation and execution of training plans for the O&M of all subsystems, equipment and software and the System as a whole, based on the O&M manuals developed above (see Section 24.3).

3.5 System Configuration

The System Performance Specification includes the definition of System configuration information, such as:

- The route alignment
- A track plan
- Key operating requirements
- System operating pattern (System capacity, station boarding and alighting and Service Interval requirements for different times of day and days of the week)
- Train configuration constraints.

These parameters are used as a basis for the calculation and specification of other System quantities and performance requirements included in this Specification. They will also be the basis for System design and performance data to be included by the Contractor in proposals and / or in SDR submittals.

For demonstration purposes hypothetical values of these parameters have been assumed herein. These hypothetical values shall be replaced with actual values appropriate to the Client's desired System and are denoted throughout this document by ("project specific").

3.5.1 System Alignment ("project specific")

The alignment included herein is hypothetical and was chosen because it is typical of potential monorail alignments in terms of urban fit (horizontal curve radii and grades) and because it is of median length for monorail projects. This information shall be replaced with information from the actual System under consideration. The alignment herein is approximately 14 km long and includes 10 stations (S 01 to S 10). The horizontal and vertical alignments together with the track schematic are shown graphically in Figure 3-1 below.

Detailed tabular horizontal and vertical alignment data can be found in Appendix 2: Alignment Data.

The track plan includes:

- Stations S 01 to S 10
- Dual guideway
- A switch and a tail track behind each end station to facilitate change of train direction and track (this configuration permits shorter headway operation than switches in front of the end stations)
- Switches, turnouts, and guideway to provide access to and from the OSMF.

Contractors shall include and identify the number and location of any additional switches and turnouts required for normal operations and failure management in order to meet the requirements of this Specification, especially System capacity and System availability requirements.

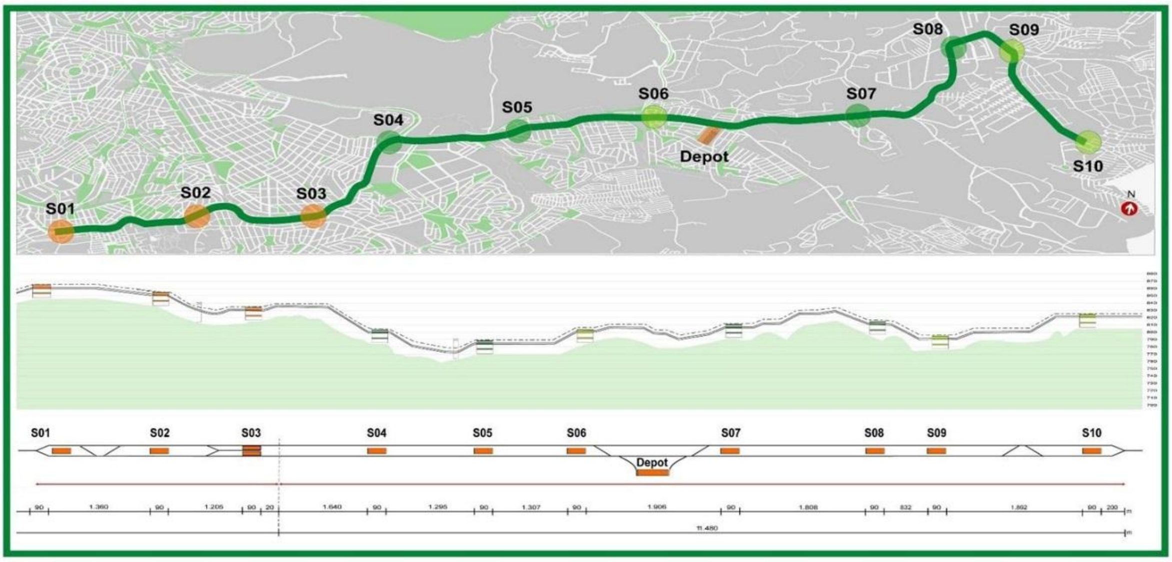

Figure 3-1: Hypothetical Horizontal and Vertical Alignment including Track Schematic

3.5.2 Key System Operating Requirements

The System shall utilize multi-car monorail trains and shall be capable of:

- Unattended Train Operation (UTO – UITP Grade of Automation 4 – GoA 4)
- Local and skip-stop operation
- Typically maximum operational speed of 80 km/h
- design speed 10 % higher than operational speed
- Typically maximum grade of 6.0 % for 500 m (higher grades may be specified in consultation with monorail system suppliers)
- Typically minimum horizontal curve radius of 50 m
- Typically minimum vertical curve radius of 500 m
- Typically minimum System operating hours of 20 per day with a System design that supports System expansion to 24 hours per day
- Recommended bi-directional trains with equal performance in either direction
- Recommended reversible train operation on the track (for example, using three Y-junction 'Schienendreieck') - reversed operation orientation (wye-junction or run-around loop)

3.5.3 System Operating Pattern ("project specific")

A hypothetical operating pattern is shown in Table 3-1 for weekdays and in Table 3-2 for weekends. This information shall be replaced with information for the actual System under consideration, ideally with peak capacity between 5,000 and 40,000 PPHPD.

The required maximum System capacity (for the current hypothetical example) is 20,000 PPHPD, which is defined to be 100 % for the purposes of Table 3-1 and Table 3-2. These tables indicate the maximum Service Intervals permitted at different times of the day. Contractors may propose to operate at shorter Service Intervals to provide the required capacities subject to alignment and monorail technology limitations.

The Operational Fleet is defined to be the number of trains required to provide the required maximum System capacity (20,000 PPHPD) at AW2, as defined in Section 9.2 or the required Service Interval, whichever is the limiting factor. The Total Fleet is defined to be the Operational Fleet plus spare trains for maintenance and standby, as defined in Section 5.1.7.

Table 3-1 System Operating Pattern Weekdays

Operating Period (h)	Required Capacity (PPHPD)	Required Capacity (%)	Maximum* Service Interval (s)
05.00 – 07.00	10,000	50	240
07.00 – 09.00	20,000	100	120
09.00 – 11.00	10,000	50	240
11.00 – 14.00	15,000	75	180

Operating Period (h)	Required Capacity (PPHPD)	Required Capacity (%)	Maximum* Service Interval (s)
14.00 – 16.00	10,000	50	240
16.00 – 18.00	20,000	100	120
18.00 – 22.00	15,000	75	180
22.00 – 01.00	10,000	50	240

*Shorter Service Intervals may be proposed

Table 3-2 System Operating Pattern Weekends

Operating Period (h)	Required Capacity (PPHPD)	Required Capacity (%)	Maximum* Service Interval (s)
05.00 – 09.00	10,000	50	240
09.00 – 16.00	15,000	75	180
16.00 – 01.00	10,000	50	240

*Shorter Service Intervals may be proposed

3.5.4 Station Boarding and Alighting Requirements ("project specific")

The design of passenger stations, station equipment, and train operations shall consider the maximum number of passengers per hour expected to board and alight trains in each direction at each station. The data (for the hypothetical System) can be seen in Table 3-3 for the weekday morning peak hours and in Table 3-4 for the weekday evening peak hours. These data shall be replaced with the appropriate data for the Client's desired System.

Table 3-3 Station Boarding and Alighting (pph) – Weekday Morning Peak Hour

Station	Westbound Boarding (pph)	Westbound Alighting (pph)	Eastbound Boarding (pph)	Eastbound Alighting (pph)	Total Boarding (pph)	Total Alighting (pph)
S 01	0	6,000	3,000	0	3,000	6,000
S 02	1,000	4,000	2,000	1,000	3,000	5,000
S 03	2,000	3,000	1,000	1,000	3,000	4,000

Station	Westbound Boarding (pph)	Westbound Alighting (pph)	Eastbound Boarding (pph)	Eastbound Alighting (pph)	Total Boarding (pph)	Total Alighting (pph)
S 04	3,000	2,000	1,000	1,000	4,000	3,000
S 05	2,000	1,000	1,000	1,000	3,000	2,000
S 06	3,000	1,000	2,000	1,000	5,000	2,000
S 07	1,000	1,000	1,000	1,000	2,000	2,000
S 08	1,000	1,000	1,000	1,000	2,000	2,000
S 09	3,000	1,000	1,000	2,000	4,000	3,000
S 10	4,000	0	0	4,000	4,000	4,000

Table 3-4 Station Boarding and Alighting (pph) – Weekday Evening Peak Hour

Station	Westbound Boarding (pph)	Westbound Alighting (pph)	Eastbound Boarding (pph)	Eastbound Alighting (pph)	Total Boarding (pph)	Total Alighting (pph)
S 01	0	3,000	6,000	0	3,000	6,000
S 02	1,000	2,000	4,000	1,000	3,000	5,000
S 03	1,000	1,000	3,000	2,000	3,000	4,000
S 04	1,000	1,000	2,000	3,000	4,000	3,000
S 05	1,000	1,000	1,000	2,000	3,000	2,000
S 06	1,000	2,000	1,000	3,000	5,000	2,000
S 07	1,000	1,000	1,000	1,000	2,000	2,000
S 08	1,000	1,000	1,000	1,000	2,000	2,000
S 09	2,000	1,000	1,000	3,000	4,000	3,000
S 10	4,000	0	0	4,000	4,000	4,000

3.5.5 Train Configuration

The configuration of the monorail trains shall be selected by the Contractor to best meet the requirements of this specification, especially the System configuration requirements in this section, System operating criteria in Section 5, and the System dependability requirements in Section 8.

Trains shall comprise:

- one fixed-length set of Cars semi-permanently connected into a Basic Train Unit (BTU) (e.g. a 4 car train), or
- two or more BTU's coupled into a Multiple Unit (EMU) (e.g. a train of two 2-car BTU's).
- single car operation provided that all safety and emergency evacuation requirements are achieved. (It shall always be possible at any location on the system for a passenger to safely self evacuate from any vehicle to a safe location in the event of an emergency.)

Vehicles within a BTU shall be semi-permanently connected with a drawbar or a coupler and deploy inter-car gangways between vehicles. Trains shall have couplers at each end to permit coupling with other trains for train recovery purposes (at a minimum).

3.6 System Expandability ("project specific")

The System shall be designed to facilitate easy expansion, including:

- Increases in System capacity on the existing route
- Additional stations on the existing route
- Route extensions including branch lines.

Note to Clients: Consideration should be given to defining the System requirements such that the initial System includes a degree of expansion (e.g., design for several years ahead). It is particularly important that requirements contemplate specific expansion scenarios so that the design can anticipate them and not preclude them due to lack of space, functionality, or capacity.

The Contractor shall provide a **System Expansion Plan** to meet the future / ultimate capacity study, if provided.

The following at least items shall be considered:

- Additional fleet of existing train configuration
- Operation at reduced headway
- Increased station throughput (e.g. more fare gates)
- Adequate train storage for additional fleet at OMSF or elsewhere
- Additional train maintenance capacity (increased number of bays, equipment, staff)
- More equipment, displays, staff at Central Control Facility (CCF)
- Additional power supply and distribution equipment, typically including a second transformer/rectifier at selected power substations
- Additional ATC equipment on new fleet
- More communications and SCADA equipment on additional trains.

3.7 Accessibility

The System shall be accessible and usable by mobility impaired and handicapped persons, including those confined to wheelchairs. Physical accessibility shall be provided in all public areas of the System during all normal operations. This includes vehicles, station approaches, fare collection, toilet facilities, platforms, and vertical circulation facilities. Station parking, where provided, shall include designated handicapped spots. Special consideration shall be given to the clarity of messages from passenger information systems.

Full wheelchair accessibility is not mandated for emergency train evacuation situations, but evacuation provisions and procedures shall address the needs of those confined to wheelchairs. These shall be included in the System Operating Procedures Manual.

3.8 Design Life

System equipment including cabling and passenger vehicles shall have a design life of 30 years except as specified below:

Suspension, propulsion motors and controls	10 years
Door operating mechanism and controls	10 years
Draft gear if any	10 years
Heating, ventilation, and air conditioning (HVAC) equipment	10 years
AFC and communications equipment	15 years
ATC technology	30 years
Traction power rails	15 years
Man-Machine Interface (MMI) equipment	10 years
Fixed Facilities including the guideway, Stations, OMSF, power substations	50 years

The running and guidance surfaces of the guideway (including switches) shall have a design life of 30 years.

3.9 Urban Design Criteria

The design and construction of the System presents opportunities to enhance and complement its environment. In addition to safely providing transportation services, the fixed facilities of the System, including the guideway, stations, maintenance facilities and other wayside structures, shall afford good appearance, durability, and sensitive design in relation to the varying neighborhoods along the route. The Client may wish to give specific guidance in terms of architectural design, choice of materials etc. Furthermore, all fixed facilities design shall comply with applicable local codes and standards as required by law.

4 Systems Engineering

The Contractor shall be the single point of responsibility for the System design.

The Contractor shall employ rigorous systems engineering techniques to ensure that the System design fulfills the requirements defined in this System Performance Specification. Requirements management techniques shall be employed to provide traceability of requirements. The Contractor shall coordinate all system interfaces within and among the system technology and equipment, the fixed facilities, and the operation and maintenance plans and procedures to ensure compliance with this Specification, verification of the System, and homologation as necessary.

4.1 Systems Engineering Plan

The Contractor shall prepare and submit a System Engineering Plan to the Client in accordance with the Data Submittal Schedule in Section 26.

This Plan shall follow the standard methodology for system engineering design, realization, and verification shown in Figure 4-1.

This Plan shall describe the organization and process by which the Contractor proposes to:

- Transform the System Performance Specification plus safety, legal, and other requirements into a description of the System, including allocation of requirements, definition of System, subsystem and component performance parameters, and definition of System and subsystem configurations, through the use of an iterative process of definition, analysis, design, test and evaluation.
- Describe the approach to configuration management and design
- Integrate related technical parameters and ensure compatibility of all physical, functional and operational program interfaces
- Integrate system assurance factors such as availability, reliability, maintainability and safety into System design and realization
- Establish a Verification, Test and Acceptance (VTA) plan including homologation as required.

4.1.1 Requirements Management and Allocation

The Contractor shall ensure that the requirements of this System Performance Specification are addressed in a structured and disciplined manner as shown in Figure 4-1. That is, requirements are collected for the System and verification, or validation methods identified for each at the system level. Further, the System level requirements are translated into detailed requirements for subsystems and interfaces such that the System requirements are met when the subsystems are integrated together. This process is known as allocation of requirements. Generally, a functional description of the System is required, and the requirements are allocated to functions. The Contractor shall prepare and submit a Functional Requirements Specification describing this allocation according to the schedule of Section 26.3.

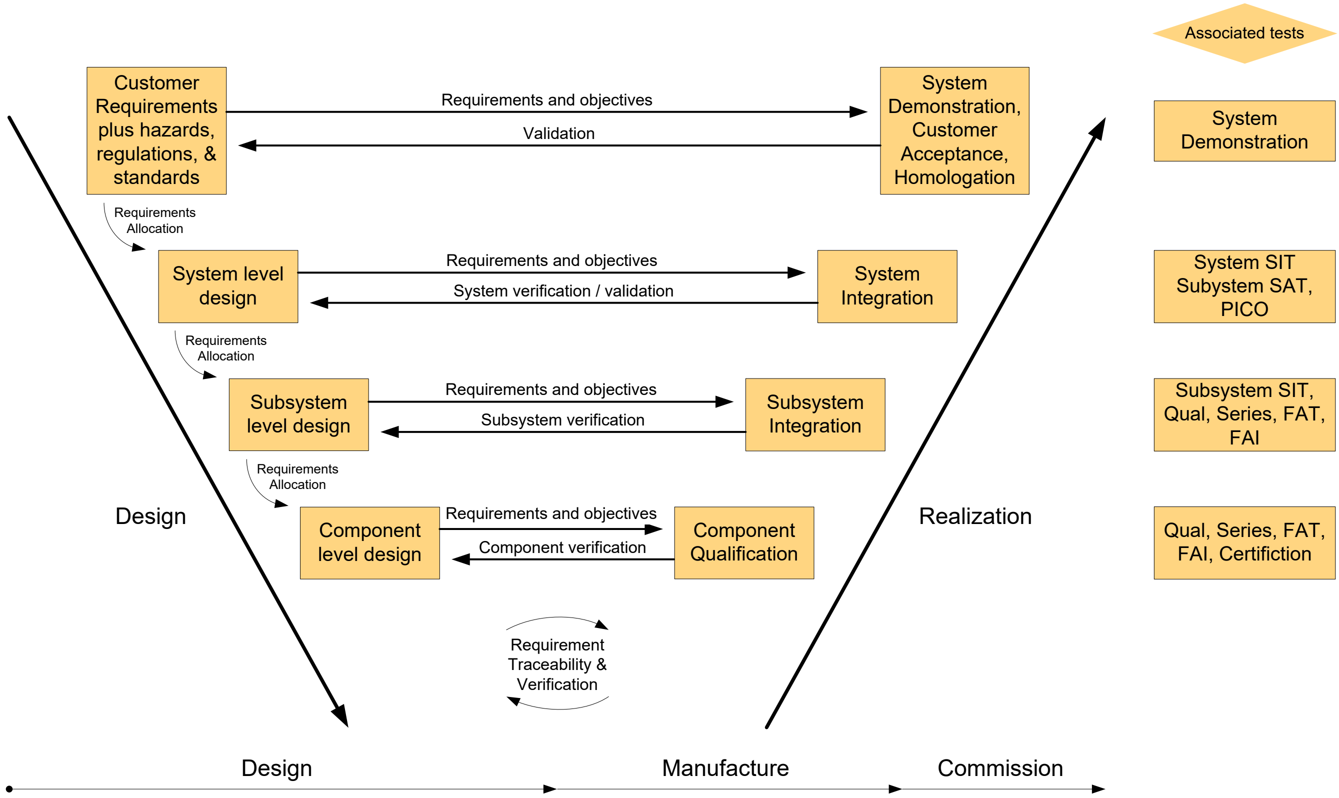

Figure 4-1: System Engineering Design, Realization, and Verification Life Cycle

Verification methods are identified for all allocated requirements. Safety functions require extra consideration and verification as described in Section 7. The allocation process continues downwards through sub-subsystems or functions to components until requirements for all subsystems, components, and interfaces are determined, and associated verification methods identified as well. Following the V-model principles, higher systems requirements might be affected by lower-level system and shall be verified. Both top-down requirements and bottom-up requirements shall be assessed for complete validation. Procurement of components can then proceed and verification to requirements can be performed, starting from receipt of components. Manufacturing, subsystems, and interfaces are verified to their requirements in turn as manufacturing, assembly, and integration progresses, finally culminating in validation of the System. Requirements allocation continues in parallel with the design process, as further requirements are identified through the design, RAM, and Safety processes. The design process is expected to employ FMEA or other techniques to identify and resolve potential failure modes at the design stage, generating verification requirements. Similarly, the RAM process is likely to generate design requirements and hence further verification requirements. The safety process as described in Section 7 generates safety requirements that shall be allocated and verified.

As an integral part of this approach the Contractor shall establish and maintain a requirements-management database to the track convergence of all requirements throughout the design, build, and commissioning phases and to confirm verification and compliance of all requirements to allow System acceptance in accordance with EN 50126.

4.1.2 System Assurance Plans

The System Engineering Plan shall outline the methodology for transforming the operational need described by the requirements of Section 4.1.1 into a description of specific System performance parameters, and for integrating the specialty engineering activities into the whole.

The Contractor shall ensure that the subsystem requirements reflect the overall requirements through the production of documents addressing key requirement and implementation plans for each discipline. These System Assurance Plans shall describe how and when supporting activities are performed. The plans to be addressed include the following:

- Safety Requirements Specification and Safety Case per Section 7.1.1
- Quality Assurance and Quality Control Program Plan per Section 23.2
- Reliability, Availability and Maintainability Program Plan per Section 8
- Availability Demonstration Plan per Section 24.2.10
- System Security Plan per Section 7.2
- Noise Control Plan per Section 6.3
- Electromagnetic Compatibility Plan per Section 24.2

4.1.3 Configuration Management Plan

The Contractor shall submit a Configuration Management Plan to the Client for information in accordance with the Data Submittal Schedule in Section 26. The Configuration Management Plan shall describe how the configuration of the System shall be controlled and documented from the proposal configuration through the design phases to as-built or as-delivered hardware and software.

4.1.4 Design Management Plan

The Contractor shall submit for approval a Design Management Plan including a Design Review Schedule, a Drawing and Document Submission Schedule and a Drawing Tree illustrating the Contractor’s drawing hierarchy in accordance with the Data Submittal Schedule in Section 26. The Design Management Plan shall include a detailed breakdown of System Technology and Fixed Facility elements. The Design Management Plan shall provide for a design review process as specified in Section 4.2 below.

4.1.5 System Interfaces and Integration

The Contractor shall define and manage the interfaces among the System elements provided by the Contractor, including System Technology plus equipment and Fixed Facility elements. The Contractor shall also identify and address interfaces between the System and the environment, which involves third parties. This management is necessary to ensure compliance to functional, safety, and other requirements as described in Section 4.1.1.

4.1.6 Verification and Test Plan

The Contractor shall provide a comprehensive Verification, Test, and Acceptance (VTA) program that ensures, by test, acceptance, or similarity, that the System, subsystems, components, and interfaces meet the requirements as given and as identified by the allocation process described in Section 4.1.1. The program shall demonstrate the proper functioning of hardware and software individually and together. The input for this program shall be in the requirements management database and the results shall be aligned with the database to generate a compliance verification matrix, as described in Section 24.

4.2 Design Reviews

The following design reviews shall be conducted jointly by the Client and the Contractor.

4.2.1 System Design Review (SDR)

The Contractor shall present a System Design Review to demonstrate compliance with the overall System requirements. As part of this review, the Contractor shall define the System-level design baseline and establish design criteria for the final detail designs of the defined subsystems and subsystems thereof.

The System Design Review shall be presented in accordance with the Data Submittal Schedule in Section 26.

4.2.2 Preliminary Design Review (PDR)

A preliminary design review shall be conducted on each of the defined major subsystems and components, in accordance with the Design Management Plan (Section 4.1.4). The purpose is to establish that the basic design is consistent with the contract documents and provide approval to proceed to final design. The material to be reviewed shall include the following, to the extent applicable:

- Scope of services
- System analysis report
- Preliminary drawings including general arrangements and/or schematics including interfaces and functional arrangement of major components
- Renderings, if applicable
- The various plans and analysis required by this System Performance Specification document.

The design reviews shall be performed in accordance with the Project Schedule and the Design Management Plan and shall demonstrate how requirements of subsystem and super system are met.

4.2.3 Final Design Review (FDR)

These reviews shall be conducted on each of the defined System's elements and for each section of the System to confirm finished documentation and incorporation of all previous design reviews leading to a definition of that section of the System. The purpose of the FDR is to ensure that all comments and action items from the previous reviews have been resolved, and to permit the Contractor to proceed to manufacture the items under the said FDR. The material to be reviewed for the FDR shall include:

- Design details

- Calculations and analyses
- Interface drawings including installation provisions.

The design reviews shall be performed in accordance with the approved Project Schedule and Design Management Plan.

4.3 Design Documentation

4.3.1 Submission of Information – General

The Contractor shall prepare and coordinate relevant documentation such as design, general arrangement and detail drawings, other technical literature, calculations, schedules, programs, samples, patterns, and models for the design reviews.

4.3.2 Submission of Information to the Client

Drawings, diagrams, calculations, and all other documents presented shall comply with the following:

a) Drawings, diagrams, and other information shall be submitted on standard sizes. Drawings shall be titled, numbered, dated, marked with the contract number, properly approved, and where applicable, include a graphical scale.

b) Calculations, schedules, and documents shall have a front cover sheet stating the title, date, document reference number, and contract number, except where existing documentation is being presented for reference.

c) Technical details of equipment to be installed in an area shall be supplied at the same time as the equipment general arrangements and layout drawings for the area are submitted. Such details shall include all space requirements for installation, maintenance and replacement, service connections required, weights, foundation, and fixing details.

d) When schematics or diagrams are submitted, they shall be accompanied by all necessary supplemental information to describe the function and operation of the equipment. When information is submitted, and the Contractor proposes technical details that are not compliant with the System Performance Specification or other contract documents, the Contractor shall identify non-compliant items and demonstrate to the satisfaction of the Client that the alternative details meet requirements that are equivalent to those specified in the contract documents.

e) When information is revised and re-submitted, the revisions shall be clearly marked and defined, and the document reference number shall identify the revision status and include a brief description of the revision. The letter of submission shall identify the drawing with revision identification.

f) Contractor submittals and re-submittals of information, including sub-contractor information, shall be checked, reviewed, and approved, as applicable, for adequacy and accuracy by the Contractor's designee prior to submittal to the Client. Detailed manufacturing drawings, manufacturing process instructions, and other data deemed proprietary by the Contractor shall be made available for inspection at the Contractor's site if the Client so requires.

The list of documents that will be submitted to the Client for review and information is included in Section 26 below.

4.3.3 Approvals/Comments, Submittal Schedules, and Other Information

For submittals requiring Client approval, the Contractor's schedule shall allow for a period of fourteen (14) calendar days from the date of receipt of the submittal by the Client to the issue of comments and/or approval, as applicable, by the Client. For documents that are issued for Client approval, in the event that the Client does not issue a response within fourteen days of receipt of the submittal from the Contractor, the submittal shall be deemed to be approved. There may be certain situations where the Client needs additional time to comment/approve beyond the fourteen days from receipt of the submittal. In such situations, the Client shall notify the Contractor of the duration within which it will respond to the Contractor and will ensure that the approval does not impact Contractor's progress.

After review by the Client, the Contractor will be informed of the notation into which each drawing or other item of information is placed according to the following:

- Notation 1: Approved
- Notation 2: Approved with comments. Work may proceed subject to incorporation of comments.
- Notation 3: Not approved. Re-submittal required. Work may proceed at Contractor's risk.

Drawings and other documents returned to the Contractor marked with Notation "3" shall be resubmitted to the Client not later than 14 calendar days after the date of receipt by the Contractor. The Client in turn shall respond to the re-submittal within 14 days of receipt of the resubmission according to the procedure stated above in this section.

The Contractor shall prepare a written response to comments received on drawings and other documents that are returned to the Contractor marked with Notation 2, stating its agreement or otherwise with incorporation of the comments.

The Contractor shall be responsible for preparing and updating a Contract Drawing List and a Contract Document List showing the title, number, revision, and current status of approval (where applicable) by the Client.

The list of documents that will be submitted to the Client for review and approval is included in Section 26 below.

4.3.4 Drawing Requirements

4.3.4.1 Types of Drawings

Drawings submitted for Design Reviews shall be updated to As-Built status and shall include the following:

- A Drawing Tree showing how all the drawings fit into the package
- Arrangement Plans showing the arrangement of facilities, equipment or components in the rooms, racks, junction boxes, housings, cabinets or modules, details of contact and terminal arrangements, assignments, and the identification of circuits. Show all spare contacts, terminals, and wires
- Key Plan Drawings describing the physical location of all equipment
- Installation Drawings including preliminary information for installation of equipment, including their interfaces with associated equipment and structures

- Cable Plans which indicate point to point cable runs and identify cable makeup and conductor wire size
- Circuit Drawings showing any/all types of control; operating and indication circuits, including description of the particular functions performed by the circuits. Show spare wires on the corresponding circuit drawings
- Single Line Diagrams and metering/relaying diagrams of AC and DC distribution systems or subsystems, including wire sizes
- Wiring Diagrams showing the details of electrical components for all pieces of equipment. Show point to point wiring details for all connections regardless of the locations
- Interface Control Documents (ICD) showing interfaces among the various works comprising the System
- Software Documentation including functional descriptions.

4.3.4.2 Dimensioning

Drawings shall be dimensioned in SI (System International / Le Systeme International d'Unites) units. Electrical schematics shall be drawn in accordance with IEEE standards or equivalent and need not be shown with components physically oriented.

4.3.4.3 Title Blocks

Drawings developed for the Contract shall provide a title block that as a minimum includes the project title and number, brief descriptive title for the drawing and space for signatories and approval by the responsible individuals.

4.3.5 As Built / Record Drawings

As-built/record drawings include top level and subassembly manufacturing and as-installed drawings. As-built information shall be incorporated on all Contractor furnished drawings as the Works are completed and shall be submitted to the Client in accordance with the Data Submittal Schedule in Section 26.

4.4 System Interfaces

4.4.1 General

The Contractor is responsible for coordinating within its scope of supply to identify and successfully meet all interface requirements to provide a System that fulfills the requirements of the Contract Documents.

The coordination work includes preparing a general interface document, documenting multiple subsystem interface requirements, flowing interface requirements to all applicable third parties and suppliers, reviewing and commenting on interface design documentation by others, and coordinating with the Client and third parties.

4.4.2 Civil Interface Document

The Contractor shall issue and submit to the Client a Design/Construction Interface Manual (DCIM) with sufficient details so that the fixed facilities may be properly designed and constructed to accommodate the System Technology and equipment in accordance with the Data Submittal Schedule in Section 26.

The document shall reference additional interface documents and documents that integrate construction, installation, and testing.

The DCIM shall be reissued as information is updated and changes occur.

4.4.3 Interface Communication

The Contractor shall create an organizational structure that ensures coordination among E&M subsystems, between E&M subsystems and fixed facilities and between the Project and other parties.

This organizational structure shall ensure formal exchange of engineering information among all parties and for design review by the relevant parties.

4.4.4 Fixed Facility Design Coordination

The general process of fixed facilities design and integration includes the development of Combined Service Drawings (CSDs). It is expected that there will be three categories of CSDs.

- The first category is based on conceptual guideway and facility design. Depending on the particular element, there shall be either a formal preliminary design review or a review by the appropriate parties with mark-ups
- The second category will include equipment layout and placement and provide detailed interface information. After review and amendment of the drawings, these drawings form the basis for construction and installation
- The third category is produced during the construction phase and includes final updates and on-site requirements.

5 System Operating Criteria

The required System operating characteristics, modes of operation, operating procedures and failure management strategies are described in Section 5.1 below. To demonstrate conformance with these requirements and the System Performance Specification generally, the Contractor shall conduct a System Operation and Fault Recovery Plan (SOFRP) supported by a System Performance and Failure Management Analysis (SPFMA). The contractor shall be responsible for operating training. These shall include descriptions of:

- Revenue service operating plans and strategies for normal operations, failure management, and emergency responses
- Train operations, field operations, OMSF, and workshop operations
- Facilities provided to perform operations effectively.

5.1 Operating Characteristics

5.1.1 System Operating Hours

The System shall provide passenger service as defined in Section 3.5.3. Scheduled wayside and guideway maintenance which otherwise would interfere with passenger service, or require reduced passenger service, shall be planned for periods with no operation. Special consideration with 24/7 operation is required to plan operation with minimal impact to system performance.

5.1.2 System Design Headway and Service Intervals

Headway shall be the time elapsed between a specific feature on one train passing a reference point on the wayside and when the same specific feature on the next train, traveling in the same direction on the same track, passes the reference point on the wayside. The System Design Headway (SDH) shall be the minimum sustained Headway possible with trains loaded to AW2 in passenger service (as defined in 9.2), experiencing nominal line voltage, and including the station dwell requirements described in Section 5.1.3. Each train will be achieving minimum link time, the designed Station Dwell Times, and not interfering with any other train (the principle of non-interference). This means that from a control perspective, each train operates independently of all other trains.

The System Design Headway shall be defined by capacity and service requirements. The system shall be capable of minimum system headway of 120 seconds.

The Service Interval shall be the planned, or operational, headway at which the System will supply a particular line capacity. From a passenger's perspective, it is the scheduled interval between the departures of successive trains in the same direction at a particular station platform. The minimum Service Interval shall be at least 5 % greater than the System Design Headway (to accommodate unscheduled delays).

The required maximum Service Intervals are specified by the day and time of day in Table 3-1 and Table 3-2.*Shorter Service Intervals may be proposed

These maximum Service Intervals are specified to ensure reasonable service even when passenger volumes are low.

5.1.3 Station Dwell Time

The Station Dwell Time shall be defined as the elapsed time from the time that the train is first stationary in a station (wheel stop) to the time when the wheel starts to rotate again to leave that station in passenger service (wheel stop to wheel start). At stations with Hot Berthing (a train waiting to leave when a train arrives) then the Station Dwell Time shall be defined as the time the wheel stops on the arriving train to the time the wheel starts on the departing train. The Station Dwell Time shall be comprised of two components, the Dwell Door Open Time, and the Station Dwell Reaction Time.

The Dwell Door Open Time shall be the time from when the last door reaches a 1 m* clear opening to the time the last door closes to a 1 m clear opening. If installed, then platform screen doors shall be included in the requirement. (*1 m door opening defined by minimum width for wheelchair access when passenger usually start moving bi-directional).

The Station Dwell Reaction Time shall be the sum of all other delays between wheel stop and wheel start.

The Dwell Door Open Time may vary from station to station. The Dwell Door Open Time shall be calculated using the number of passengers boarding and alighting at each station stop and a passenger flow rate of 1.365 passengers per metre of door width per second. If the calculation indicates less than 10 seconds then the Dwell Door Open time shall be 10 seconds, otherwise the Dwell Door Open Time shall be set to the calculated value. Dwell times at individual stations shall be adjustable from the control center in 1 second increments using the ATS subsystem. There shall also be the capability from the Control Center of extending the dwell time indefinitely for any individual train or for all trains that are in Service. During times when excess capacity exists the dwell at the end stations may be increased in order to keep travel times low and to reduce fleet mileage and energy.

5.1.4 Travel Time, Round Trip Time, and Commercial Speed

The station-to-station travel time between adjacent stations on a route shall be defined as the time elapsed from when the wheel starts to rotate when leaving the originating station to the time the train is first stationary (the wheel stops) in the destination station (wheel start to wheel stop). Station Dwell Times are not included in station-to-station travel times.

The round-trip travel time shall be defined as wheel-start to wheel-start of the same train at the same station/point on the route of a completed system round trip. The round-trip time represents the time it takes to complete one circuit, stopping and dwelling at all stations. Hot berthing at terminal stations may reduce round-trip time (per Section 5.3). Commercial Speed shall be defined as the distance travelled in a round trip divided by the round-trip time. The rear turn-back distance, if needed for standard operation is included in the travel distance if the rear turn-back is not included in the Station Dwell time.

In order to ensure that trains can maintain a given service level with a high degree of certainty, a dwell envelope (maximum and minimum above and below the nominal dwell in effect at the time) is used to manage normal perturbations in service.

In actual operations, the ATS or a CCO shall be able to adjust the round-trip times to obtain smoother operations throughout the System and to manage service perturbations, as described in Section 11.3.3.3.

5.1.5 Vehicle and Train Design Capacity

The Contractor shall perform all travel time and fleet size calculations with trains loaded at AW2 capacity as defined in Section 9.2 and using the weight per passenger as defined in the same section.

5.1.6 Line Capacity

Line capacity is the number of passengers per hour per direction (PPHPD) that can be carried past a given point by nominally loaded trains as specified and operating at the prescribed nominal Service Intervals. The required line capacities by day and time of day can be found in Table 3-1 and Table 3-2.

5.1.7 Fleet Size, Train Length, and Spare Vehicles

The Service Interval requirements and the line capacity requirements of Section 5.1.6 shall be used by the Contractor to establish the operating fleet size.

The contractor shall propose a Rolling Stock Fleet size sufficient to meet the prescribed Train Service Plan(s) demands while at the same time achieving all contractual operational Performance Regimes and Customer Experience measurements. If nothing is specified a conservative rule is a number of spare trains shall be at least 10 % or two trains, whichever is larger.

The rule of thumb was a spare ratio of 10 % and a methodology as follows:

Service Fleet to meet Service Plans	7 % (scheduled)
Maintenance	1 % (unscheduled)
Hot Standby (Guard)	1 % (availability, 'speed of reaction')
Spares	1 % (The 10 %) (risk, accident vehicles, unforeseen)
Fleet size	10 % (round up to nearest integer)

Each category shall have at least 1 train and the sum of all categories shall round up to nearest integer number of trains.

The Contractor shall conduct a System Operation and Fault Recovery Plan (SOFRP) and a System Performance and Failure Management Analysis (SPFMA) to demonstrate analytical conformance with the requirements of this performance specification including requirements for System availability. The SPFMA shall accurately predict the operation of the trains on the System using mathematical techniques. Requirements for the SPFMA include those listed in the following Sections 5.1.7.1 and 5.1.7.2 below.

5.1.7.1 Input Parameters

- Predicted train performance considering vehicle Design Capacity requirements of Section 5.1.5 propulsion system characteristics, train resistance and braking characteristics, and the ride comfort requirements
- Guideway characteristics for the route including vertical and horizontal curves, crossover switches, stations, and any speed restrictions
- Station Dwell Times resulting from the application of the requirements of Section 5.1.3

- Line capacity requirements for the System as described in Section 5.1.6. Service Intervals for the System as described in Section 5.1.2
- Predicted failures for train and wayside equipment on all relevant guideway sections and at each station platform considered singly
- The locations of guideway switches, pocket guideway, or similar failure management facilities.

5.1.7.2 Output Parameters

The results of the SPFMA shall define System operating characteristics for normal and failure management modes of service and shall include all data required to define operation. The results shall include:

- Minimum and planned roundtrip time
- Line capacity
- Station Dwell Time
- Minimum Service Interval and planned headway
- Train velocity (commanded and simulated), and running time continuously presented as a function of route position
- The probability and average duration of each type of failure, and the effect on other trains for each type of failure, on each guideway section and each station platform. The effect shall consider delays and shall state the maximum delay
- The recommended set of failure management routes, which will be selectable by the Central Control Operator, to avoid an obstruction on each section of the guideway. These routes shall be controlled by the ATC system including train turn-back at the extreme ends of the routes, and control of all interlockings
- A description of the proposed failure management modes and operations
- The resulting levels of service and capacities during failure management operations
- The minimum and average time between service-affecting failures and System availability.

The Contractor shall prepare the preliminary SPFMA based on actual System design and submit a final SPFMA as part of the System Design Review.

5.2 System Operating Modes

The hypothetical System included herein is a pinch-loop configuration, and the following requirements on operating modes reflects this. Should the actual desired System be another configuration the mode requirements shall change.

Operating modes shall include at least:

- Single-pinched loop for normal operations
- Double-pinched loop with an intermediate station being common to both loops and acting as the short-turn-back station for the shorter of the two loops for normal operations. The extent that such short-turn-back services can be established will depend upon the quantity and locations of crossovers provided

- Contingent operating modes (shuttles) for failure management and unscheduled guideway maintenance.

The System, for all proposed train lengths, shall operate in each of these modes as specified in Sections 5.2.1, 5.2.2, 5.2.3, 5.2.3.1, 5.2.3.2 and 5.2.4 below.

5.2.1 Normal Operating Mode

The normal routing of trains will involve movement on a double track alignment in circulating or pinched-loop mode, with trains operating between two terminal stations. All trains stop at each station on their route. At the terminal stations, the trains shall crossover to the other guideway lane for the return run.

The “normal”, or nominal, direction of travel will follow the practice of right-hand running. That is, trains will normally travel in a counter clockwise direction when viewed from above, for forward operations on the right-side lane of the dual guideway.

All sections of the System shall permit train movements in the opposite direction to the normal direction of travel (that is, shall permit bi-directional operation) to permit single-tracking and shuttle operations as required in Section 5.2.3.

Pinched-loop mode shall be an automatic and regulated operation. In this mode, the Service Interval shall be regulated. The Station Dwell Times shall normally be based on the Operating Plan. The ATS system or a CCO shall be able to adjust the Station Dwells to obtain smoother operations throughout the System and to manage service perturbations, as described in Section 11.3.3.3.

5.2.2 Double Pinched Loop (Short-Turn-Back) Mode

In addition to the normal mode of operation, it shall be possible to establish short-turn-back routes using intermediate crossover switches. It shall be possible to assign trains to a line that extends beyond the short-turn-back station versus trains that will turn around at the short-turn-back station. The ATC system shall regulate the merging of the trains at the common point of the Mainline to ensure that trains operate at the prescribed Service Interval in the common portion of the System.

All requirements for the normal mode of operation described in Section 5.2.1 shall apply with the short-turn-back mode.

The extent that such short-turn-back services can be established will depend upon the quantity and locations of crossovers provided.

5.2.3 Contingent Operating Modes

In addition to the pinched-loop mode, contingent-operating modes shall be provided for service adjustments, failure management and unscheduled guideway maintenance during the off-peak periods. The extent of the contingent-operating modes shall be determined by the Contractor and included in the SPFMA of Section 5.3.

Contingent-operating modes shall include at least skip-stop and shuttle mode, as follows.

5.2.3.1 Skip-Stop Mode

An express, skip-stop mode shall be provided for the purpose of re-instating service to parts of the System after a major delay or slowdown. In skip-stop mode, the Central Control Operator shall have the capability to permit ATO trains to travel non-stop through (or skip the stop at) selected stations, at the maximum permissible station pass-through speed.

5.2.3.2 Shuttle Mode

This automated mode shall permit a single train to travel back and forth between any two stations. In shuttle mode, the Central Control Operator shall have the capability to select a start station, an end station, and a route, which will allow a single train to stop at all intermediate stations along the route in addition to the start and end stations.

It shall be possible to combine skip-stop mode and shuttle mode.

It shall be possible to establish multiple shuttle-mode services operating concurrently. These shuttles may not overlap, except for the end stations on the shuttle routes.

5.2.4 Operational Overrides and Adjustments

It shall be possible to override and adjust the automatic operation of the System in all modes by commands from Central Control. When imposed, System overrides or adjustments, except for single, one-time train or station overrides, shall remain in effect until removed by the Central Control Operator.

The System shall have the capability to be operated in “Station Ahead Clear” mode wherein a train will not depart a given station until access to the next station is assured, and there is no vehicle in the next station or on route to it. This functionality shall not be the normal operating mode, but available as an option to the Central Control Operator.

5.3 Failure Management

During the design of the System, its component equipment and its attendant operating and maintenance procedures, the Contractor shall anticipate the disruptive potential of failures and take steps required to minimize their impact on passenger service. In support of this, the Contractor shall prepare a Fault Recovery Plan as a part of the System Operating and Fault Recovery Plan (SOFRP). The Fault Recovery Plan shall use the theoretical analysis presented in the SPFMA as a basis.

The Fault Recovery Plan shall detail the most effective ways of returning the System to normal operation following faults that are disruptive to passenger service. The plan shall consider not only contingent modes of operation, but also manual intervention, which may be required prior to, or in conjunction with, the contingent mode of operation to be employed.

The plan shall also address the procedures, means and/or alternatives to be employed to:

- Evacuate passengers safely from trains stalled on an elevated section of the guideway between stations
- Recover trains stalled on any area of the guideway.

The plan shall address evacuation under supervised conditions, when passenger lives are not threatened, and both supervised and unsupervised evacuation, under emergency conditions, and when passenger lives may be threatened.

5.4 System Startup, Shutdown, Transition and Restart

5.4.1 System Startup

The System shall be started into automatic operation by action of the Central Control Operator; after which trains shall be dispatched automatically for the commencement of revenue service. Consistent with operational requirements, trains shall be placed in position at, or near, stations along the guideway that will space them approximately one Service Interval apart prior to the initiation of service.

Procedures shall be developed to ensure that trains entering revenue service do not pose a threat to maintenance personnel, are safe, functional, and meet the prescribed cleanliness standards.

The System shall operate in the manner described in the following paragraph or as modified to meet specific operational needs as they arise.

Approximately 15 minutes prior to start of revenue service, the station gates and/or doors will be unlocked to allow passengers to access the System. At the start of revenue service, the trains positioned at stations along the guideway will open their doors for the specified dwell time. At the expiration of the dwell, the trains will close their doors and depart at their planned time for regulated service.

5.4.2 System Shutdown

Prior to discontinuing System service, announcements shall be made in all stations and trains, and appropriate signage shall be displayed in each station. Trains shall continue to operate until all passengers in the System complete their trips.

The System shall operate in the manner described in the following paragraph or as modified to meet specific operational needs as they arise.

Trains will be removed from revenue service by CCO command at the Terminal stations. Transit System personnel or automatic systems will then verify that each vehicle is empty of passengers. Upon notification that the train is empty of passengers, the Central Control Operator will then route the train to an appropriate storage location in a designated station, or to an OMSF.

5.4.3 Mode Transition and Train Adjustments

It shall be possible to route the train(s) from either OMSF or the inactive terminal-station platforms and insert the train(s) into regulated service at the prescribed Service Interval.

The transition between operating modes within the normal operating state and the insertion and removal of trains into/from passenger service shall be accomplished automatically by ATC commands and shall not require manual train operations.

The System shall not be shut down to perform transitions or train changes. System stabilization at the new headway shall occur within one scheduled round trip time. Delays to any train in Service during these actions shall not exceed one scheduled headway in duration. Before a train is removed from Service, appropriate announcements shall be made on that train and at each station it enters prior to its actual removal. If possible, the train to be removed shall continue to operate until all passengers on board at the first announcement have completed their trips.

System stabilization at a new Service Interval shall occur within one round trip of insertion of the first train during ramp up, or within one round trip of the removal of the first train during ramp down. Except for a failed train, such transitions shall be accomplished automatically by the ATC System and shall not require manual train operations. Appropriate announcements shall be made in all affected stations and trains. Operating/Maintenance personnel shall ensure that no passenger remains on any train taken out of service.

For purposes of System Availability calculations, transitions shall be considered in the calculations according to the provisions / procedures of the Availability Demonstration Test Procedures and Plan and the Operating Plan.

5.5 Maintenance Program

The maintenance program shall be designed to satisfy maintenance requirements to meet the availability goals and capacity requirements. It shall consider operating costs and life cycle maintenance costs, availability of facilities and systems, System safety, reliability, and convenience of service for passengers, and protection for employees, facilities, equipment, and parts. The maintenance program shall be comprised of a System Maintenance Plan, a set of Maintenance Manuals, and an integrated training program for staff.

5.5.1 System Maintenance Plan

The System Maintenance Plan shall include the following:

- Design, layout, and utilization of the OMSF
- Maintenance organization and staff responsibilities
- Maintenance staff qualifications and training
- A list and brief description of all maintenance manuals
- Approach to scheduling of preventive maintenance work (including overhaul work)
- Approach to corrective maintenance and the diagnostic analysis of failures
- Process of responding to reports of non-functioning systems, subsystems, and equipment and the corrective maintenance criteria for restoring these to functional status
- Preventive maintenance program
- Staff maintenance coverage
- Routine cleaning, Inspection, and Service Plan for vehicles, facilities and equipment
- Spare Parts Procurement, Cataloguing, and Inventory Control.

Corrective maintenance programs shall be based on the principle of exchanging line replaceable units (LRU) in the field, in order to reduce the mean time to repair. The System Maintenance Plan shall define the time to restore function capability for individual systems and subsystems.

5.5.2 Maintenance Manuals and Training

The Contractor shall provide Maintenance Manuals for all subsystems, facilities, and equipment in the System scope, defined in Section 3.1. The supplied Maintenance Manuals shall be integrated into the Training Program (see Section 25.3).

6 System Environmental Design Criteria

The System shall be operated, stored, and maintained as specified without impairment resulting from the environmental conditions described below occurring either individually or in natural combinations. System operations and maintenance shall not cause or induce environmental consequences greater than specified in the appropriate subsections of Section 6.

6.1 Atmospheric and Weather-related

The System shall operate under the atmospheric and weather-related conditions listed in Table 6-1.

Table 6-1 Atmospheric and Weather-related Conditions

Ambient temperature range	-20°C to 50°C
Relative humidity	Up to 100% including condensation
Rainfall	Up to 50 mm/h (see 6.5)
Snow, ice, slush, freezing rain, frost	No significant accretion
Wind speed for normal operation	Up to 75 km/h
Wind speed for degraded operation	75 – 90 km/h
Wind speed requiring discharge of passengers at next station and moving to a protected location	Above 90 km/h
Wind speed for structural integrity	Up to 120 km/h, no damage to System including trains stopped between stations.
Solar heat load	1,120 W/m^2 (equatorial load)
Atmospheric pollution	System shall not cause gaseous or particulate emissions other than trace amounts.
Lightning	Protection follows EN 50153. EMC plan shall address lightning protection (see 6.2).

6.2 Electromagnetic Compatibility (EMC)

The System, and its subsystems, shall be electromagnetically compatible with their environments. They shall not produce electromagnetic emissions, whether conducted, radiated, or induced, that interfere with the normal operation of the System. Emission levels may also be constrained by statute or by code. Reasonable measures shall be taken to mitigate the risk of interference with other equipment in the vicinity of the System, including that belonging to the public.

Conversely, the System electrical and electronic equipment shall function satisfactorily in the presence of electromagnetic emissions, whether generated by other components within the System or legally installed devices within the surrounding environment. The environment includes communications systems, microwave facilities and transmissions, television and radio transmitters and repeaters, radar systems, computer equipment and accessories, electric motors, controls, power tools, welders, x-ray equipment, power substations and equipment, electrical distribution equipment, electrical installations, HVAC equipment, automotive vehicles, and high-voltage power lines.

The Contractor shall develop an Electromagnetic Compatibility Control Plan, and it shall be noted and included in Section 24. The Control Plan shall contain the following elements:

- Interference emission and susceptibility requirements and rationale for selection, including applicable support computations
- Design techniques to reduce interference coupling
- Safety grounding protection requirements for personnel and equipment
- Lightning protection
- Electromagnetic compatibility evaluation and analysis
- Problem area definition and fix recommendation if possible
- Compliance verification requirements for operational components and associated testing equipment
- Critical compatibility demonstration requirements including critical circuit definition and success criteria
- Configuration control method.

All System transmitting and receiving equipment, such as that required for automatic train control and audio/ visual communications, shall meet any required licensing, interference, and permissible field requirements.

Frequency management techniques shall be used to minimize emission spectra and receiver bandwidths and to control frequencies, pulse rise time, harmonics, sidebands, and duty cycles as required.

6.3 Noise

The Contractor shall establish and implement a Noise Control Plan, and submit it as required by the data submission plan in Section 26. This shall identify the methodologies to be used to ensure that noise requirements for the system are met. The scope of the work will be to:

- Create a simulation model using appropriate analysis software for exterior noise, and similar for interior noise

- From the models, establish noise allocations for each major noise source (mainly, propulsion equipment, HVAC, rolling noise, air compressors)
- Review vehicle construction material selection and design of relevant elements (mostly covers, panels, insulation) to ensure proper noise attenuation
- Institute a close follow-up with vendors and designers of the relevant elements, by periodic reviews and measurements, to ensure that the noise allocations and/or attenuation are met
- Keep the models updated to avoid any slippage on the global noise targets
- Define the tire/beam interface for required traction and braking while not exceeding noise requirements.

The Contractor shall ensure that the methodologies and requirements identified in the noise control plan flow into the subsystem development requirements and are included in Section 24.

6.3.1 Wayside Noise

Exterior vehicle noise shall not exceed 75 dB (A) under the following conditions:

- Maximum length train
- Operating an open, level, tangent track
- During acceleration, cruise, and braking
- At rest and at speeds up to max operating speed
- Windows and doors closed
- Auxiliary equipment operating normally
- Measured in a free field at 7.5 m from single guideway centre and 1.2 m above top of guideway
- Measured in accordance with ISO 3095:2013(E).

Noise levels measured 1 m outside of a traction power substation with ventilation operating shall not exceed 75 dB (A).

Noise levels measured within the confines of a passenger station shall not exceed 72 dB (A) due to a station lighting and power substation with ventilation operating.

6.3.2 Interior Train Noise

Interior train noise requirements can be found in Section 9.6.2.

6.4 Vibration and Ride Comfort

Vibration and ride comfort are specified in Sections 6.4.1, 6.4.2, 6.4.3, 6.4.4 and 6.4.5.

6.4.1 Train Maximum Sustained Acceleration

Maximum sustained acceleration and deceleration are addressed in Section 9.6.3.1.

6.4.2 Train Maximum Jerk

Maximum jerk is addressed in Section 9.6.3.2.

6.4.3 Train Ride Quality

Ride quality is addressed in Section 9.6.3.3

6.4.4 Vibrations in Guideway and Support Structure

Train interactions with the guideway, the guidance and running structures and surfaces shall be considered and the design restrict the transmission of vibration through the guideway structure to the surrounding buildings and terrain during the passage of trains. System-induced vibrations shall neither damage nor be unusually high at or in surrounding buildings.

6.4.5 Train-borne Component Vibrations

Train-borne component vibrations are addressed in Section 9.6.3.4.

6.5 Precipitation, Flooding and Water Pollution

The System shall be capable of normal operations during falling rain. Operating trains shall sustain normal operations, including acceleration, service and emergency braking, and precision station stopping in the precipitation conditions of Section 6.1. The guideway and emergency walkway design shall restrict excessive accumulation of water that interferes with normal or emergency operations.

The power distribution system shall be designed to avoid the occurrence of electrical faults, interruption of power, and loss of power and grounding contact under these precipitation conditions. System equipment shall be designed to avoid the accumulation of water on, around, and within equipment and equipment compartments.

All facilities and equipment which can be damaged by flooding shall be installed above the 100-year flood level.

Where drains are required to accommodate storm water run-off from the guideway and other fixed facilities, the drains shall be routed directly into the storm drainage system adjacent to the System, if available. The quantities of pollutants dropped or deposited by the monorail vehicles that could be washed into the storm drainage system or on areas below the guideway shall be restricted, and meet the local laws, requirements, standards, ordinances, rules, and regulations governing pollution.

Discharge from activities in the OMSF, including the car wash area effluents, shall be into a sanitary sewer system. The drainage system shall contain any accidental spills prior to discharge and pre-treat all discharge (e.g., oil skimming) to meet the local laws, requirements, standards, ordinances, rules, and regulations governing water pollution.

6.6 Earthquake Readiness

Suitable measures shall be taken to comply with the earthquake readiness requirements specified in applicable building codes and relevant standards considering the location of the System.

7 Safety and Security

This section addresses requirements, principles, plans, and procedures relating to the safety and security of the System.

Distinctions are made between installations and commissioning of the System and the subsequent operation phase, as well as between safety and security. While the safety and security during operation clearly depends upon the design, installation, and commissioning of the System, the safety and security during installation and commissioning are unique and hence treated separately. Safety during System operation is addressed immediately following in Section 7.1, security during operation is addressed in Section 7.2, and safety and security during construction, installation, and commissioning is addressed in Section 7.3.

The appropriate authority has to be specified by the client or agreed at the beginning of the project (it can be national, city authority, the operator or a contracted third party) and communicated to all parties involved and strongly depends on the legal framework of the related country in place, often also called national safety agency (NSA). In general, the appropriate authority checks which laws must be applied for the commissioning of a Monorail and can also specify the applicable safety standards (e.g. EN 50126). The appropriate authority is in general responsible for issuing the building permission and the final permission to operate.

The general systemic requirements are:

- personal safety in connection with the use or presence in the system and safe evacua-tion/rescue in the event of incidents due to a defect or environmental impact (safety)
- operational safety, including in the event of defects or possible interference by third parties (se-curity), also to ensure personal safety towards third parties in the vicinity of the system

The requirements for personal safety during the intended operation are assured by recognized rules of technology, which are harmonized in the IMA specification (reference to relevant and verifiable normative requirements). This concerns the requirements for the subsystems such as the "vehicle design”, the "station design" and the "operational control".

Possible deviations from the intended operation may require special technical and operation-al/organizational measures so that passengers can safely rescue themselves or be rescued from a possible or existing danger zone. Some of the associated requirements have already been defined in the individual chapters but are summarized and justified in chapter 7.3.3 as a ‘checklist’.

7.1 Safety of the Operational System

The System shall be shown to be adequately safe prior to start of System operation. System safety shall be shown in accordance with the standard EN 50126 (or equivalent American standards such as IEC 62278) and the methodology of the standard EN 50129 (or equivalent American standards such as IEC 62425). The following excerpts and interpretations of those standards are intended as a guide to the Contractor.

Generally, the following acceptance limits are defined, which can also be adapted in the event of national requirements or operational particularities or requirements of the company's safety management system. The competent authority/institution or the commissioned Overall Independent System Assessor (OISA) should confirm the adjustment after examining the systemic and operational risk analysis, so that there is an assured basis for planning and authorization. An Overall Independent Safety Assessor (OISA) is an independent body that assesses and certifies the safety of the full lifecycle of an entire Monorail system, including all relevant interfaces between the various subsystems, e.g. infrastructure, signaling.

A typical safety recommendation of public transport is that the system should be accessible and usable for all passengers, including persons with reduced mobility (PRM) such as e.g. those unable to walk or passengers with impaired perception e.g. blind or deaf passengers, as well as dependent passengers, e.g. travelers with children.

Subsequently the risk acceptance limits (residual risk) regarding personal safety and operational safety are presented. In general, a residual risk is a risk remaining after risk control measures have been taken and must be agreed by the operator and the appropriate authority, if existing.

Risk acceptance categories regarding personal safety (see examples related to safety also in Table C.9 of the EN 50126-1:2017):

1. physically noticeable impact (e.g. bruise) or minor injury possibly combined with outpatient treatment (e.g. contusion, sprain) are acceptable (i.e. insignificant),
2. possible serious injury (e.g. broken bone, concussion) associated with inpatient treatment and longer treatment time should be avoided in the case of incidents (e.g. crash, fall) (i.e. marginal),
3. a single accidental death and/or several critical injuries combined with lengthy hospitalization and possibly permanent physical injury (e.g. necessary amputation, paralysis) are not acceptable and must be prevented

   and

4. self-rescue of each person must be assured before a health-critical effect and without further health risks during the rescue to a safe area (if necessary combined with mutual assistance),
5. external rescue must be assured as quickly as possible to avert health hazards and to help passengers who are no longer able to move (usually in conjunction with auxiliary equipment and trained personnel/rescue workers).

Acceptance limit regarding operational safety:

6. The mitigating solution, e.g. as a result of an internal system error, should be limited to one hour, if possible (this also with reference to the requirements for rescuing passengers).
7. in the event of possible extreme environmental influences, operations must be interrupted based on the specific conditions on site to protect passengers, vehicles and infrastructure as a pre-cautionary measure,
8. potential interference by third parties (mechanical regarding vandalism or terrorism, software-specific regarding cyberattacks etc.) shall result in bringing the system to a safe situation for all passenger and subsystems.

7.1.1 Safety Acceptance and Approval

For safety acceptance and approval, the Contractor shall show adequate evidence of safety to a Safety Assessor. The evidence of safety shall be in three categories:

1. Evidence of quality management,
2. Evidence of safety management,
3. Evidence of functional and technical safety.

The documents showing that evidence shall be:

- The System Requirements Specification
- The Safety Requirements Specification
- The Safety Case
- The Safety Assessment Report.

The Contractor is responsible for the System Requirements Specification, the Safety Requirements Specification, and the Safety Case.

The Safety Assessor is responsible for the Safety Assessment Report. That report will explain how the Safety Assessor determined that the System was designed to meet its specified requirements, down to through the subsystems and equipment to the components, including software. The Safety Assessor may require some specific tests or analyses to increase confidence and may specify some additional conditions for operation of the System. Typically, the Contractor will identify compliance with a recognized standard as proof of meeting requirements. The Safety Assessor shall be the arbiter of the adequacy of such arguments.

7.1.2 After Safety Approval

As stated in EN 50129, after the System has received safety approval, any subsequent modification shall be controlled using the same quality management, safety management and functional/technical safety criteria as was used for a new design. All relevant documentation, including the Safety Case, shall be updated, or supplemented by additional documentation, and the modified design shall be submitted for approval.

Once the System has been commissioned, appropriate procedures, support systems, and safety monitoring, as defined in the Safety Plan and in Section 7.1.7 of the Technical Safety Report (part of the Safety Case), shall be used to ensure continued safe operation throughout its working life, including operation, maintenance, alteration, extension, and eventual decommissioning.

These activities shall be controlled using the same quality management, safety management, and technical safety criteria as for the original design. All relevant documentation shall be kept up to date, including the Safety Case and any alterations or extensions shall be submitted for approval.

7.1.3 The Safety Case

The Safety Case is a structured document justifying the safety of the System. The Contractor will provide a specific Safety Case for the System to obtain safety acceptance and approval according to the schedule in Section 26.3. The specific Safety Case may reference generic and / or product Safety Cases for products, subsystems, equipment, or components to support the System specific Safety Case provided those generic and / or product Safety Cases have been previously approved by an acceptable authority and assessor and are applicable. All Safety Cases provided shall have the following structure:

Part 1. Definition of the System (or product, subsystem, equipment, or component)

Part 2. Quality Management Report

Part 3. Safety Management Report

Part 4. Technical Safety Report

Part 5. Related Safety Cases

Part 6. Conclusion

The definition of the System (or product, subsystem, equipment, or component) does not need to be a document specific to the Safety Case (it may have multiple uses), however it shall precisely define the System (or product, subsystem, equipment, or component) to which the Safety Case refers. The definition shall include the version numbers and modification status of all requirements, design, and application documentation.

The Quality Management Report shall show adequate evidence of an effective quality management process, as discussed in Section 23.

The Safety Management Report shall show adequate evidence of a Safety Management Process, as discussed in Section 7.1.4.

The Technical Safety Report shall show adequate evidence of functional and technical safety, as discussed in Section 7.1.7.

The related Safety Cases in Part 5 of the Safety Case shall provide all generic or product Safety Cases that are referenced to support the main Safety Case and shall also demonstrate that all the safety-related application conditions specified in each related Safety Case is either fulfilled in the main Safety Case or carried forward into the safety-related application conditions of the main Safety Case.

The conclusion in Part 6 of the Safety Case shall summarise the evidence presented in the previous parts of the Safety Case, and argue that the System (or product, subsystem, equipment, or component) is adequately safe, subject to compliance with the specified application conditions.

7.1.4 Safety Management Process

The Contractor shall have a Safety Management Process and provide adequate evidence of same in the Safety Management Report part of the Safety Case. The Safety Management Process shall include:

- A safety organization
- Generation of a Safety Plan
- Safety requirements identification and allocation
- Generation of a safety requirements specification

- Generation and maintenance of a Hazard Log
- Conduct and documentation of Safety reviews
- Safety requirements verification and validation
- Generation of Safety justification (the Safety Case)
- System/subsystem/equipment safety acceptance
- Operation and maintenance change request safety process
- Decommissioning safety process.

The Safety Organisation shall have appropriate independence, as described in Section 7.1.5.

A Safety Plan shall be prepared and submitted according to the schedule in Section 26.1. The Safety Plan shall identify the Safety Organisation structure, a Safety Case plan, and safety-related activity and approval milestones including review of the Safety Plan at appropriate intervals. The Safety Plan shall be updated and reviewed if subsequent alterations or additions are made to the original System, subsystems, equipment, or components. If any such change is made, the effect on safety shall be assessed, starting at the appropriate point in the life cycle.

Safety requirements shall be identified, allocated, and specified as described in Section 7.1.6.

The Safety Management Process shall include preparation and submission of a safety requirements specification according to the schedule in Section 26.3. The Safety Requirements Identification, Allocation, and Specification process of Section 7.1.6 will provide the requirements to be specified. The safety requirements specification may be a separate document, or it may be a subset of the System functional requirements specification of Section 4.1.1.

The Safety Management Process shall include generation and maintenance of a Hazard Log, to be reviewed with the Client during safety reviews, and submitted according to the schedule in Section 26.3. The Hazard Log shall include a list of identified hazards, together with associated risk classification and risk control information for each hazard. The Hazard Log shall be updated during the design and implementation process and if any modification or alteration is made to the System, subsystems, equipment, or components. All safety requirements generated by the Hazard Log creation and maintenance process shall be added to the safety requirements specification and the verification process.

The Safety Management Process shall provide and document plus action the results of safety reviews at reasonable points documented in the Safety Plan.

The Safety Management Process shall ensure verification and validation of the safety requirements. It is expected that verification and validation of safety requirements will be incorporated into the overall verification process of Section 24, however the Safety Management Process shall ensure the independence requirement described in Section 7.1.5., and also ensure documentation of the verification and validation of safety requirements in the Safety Case.

The Safety Management Process shall ensure the justification of System safety, that is, generation of the Safety Case, and the safety acceptance of the System and all subsystems, equipment, and components as described in Section 7.1.1.

The Safety Management Process shall ensure the existence and effectiveness of a Safety Review Process for all change requests in both operation and maintenance of the System. Where a change request results in a modification which could affect the safety of the System, or associated systems, or the environment, the appropriate portion of the safety life cycle shall be repeated to ensure that the implemented modification does not unacceptably reduce the level of safety.

The Safety Management Process shall ensure that decommissioning and disposal at the end of the operating life shall be carried out in accordance with the measures defined in the Safety Plan and in Part 5 of the Technical Safety Report.

7.1.5 Safety Organisation and Independence

A Safety Organisation shall be defined, with competent personnel assigned to specific roles. Assessment and documentation of personnel competence, including technical knowledge, qualifications, relevant experience, and appropriate training, shall be carried out in accordance with recognised standards.

An appropriate degree of independence shall be provided between different roles in the Safety Organisation. For all safety functions a Safety Assessor is needed.

For SIL 0 safety functions the manager may supervise the designer and the verifier, and the designer and verifier can be the same person. However, to ensure good engineering practice this System Performance Specification requires that the verifier shall be a different person than the designer. The Safety Assessor will only be involved in SIL 0 safety functions if overall System safety could be affected.

For SIL 1 safety functions the manager may supervise the designer and the verifier, and the designer shall not be the verifier. That is, a person may not verify their own design.

For SIL 3 and 4 safety functions the manager may supervise the designer and the subsystem, component, and requirements allocation verifiers however the verifier shall not be the designer. That is, a person may not verify their own design. A verifier not supervised by the manager of the designer(s) shall verify the System level requirements. That verifier may be in the same organisation as the manager.

At the discretion of the Safety Authority (as identified by the Client), the Safety Assessor may be part of the supplier's organisation or of the Client's organisation but, in all cases, the Safety Assessor shall:

- be authorised by the Safety Authority
- be totally independent from the project team
- report directly to the Safety Authority.

7.1.6 Safety Requirements Identification, Allocation, and Specification

The Contractor shall define safety assumptions and use the System functions defined in Section 4.1.1 to identify hazards, and to assess and classify risks (risk analysis). Hazards will be entered in the Hazard Log. The ALARP principle (as low as reasonably practicable) principle shall be used to evaluate risk levels. In some cases, equivalent principles such (e.g., Germany) the minimum endogenous mortality (MEM) can be used. The Contractor will propose tolerable hazard rates (THR's) for safety functions to the Client. The Client may, in parallel, request THR's and / or Safety Integrity Level assessments for major safety functions from a third party. The Contractor will work with the Client, his agents, and the Safety Assessor to define acceptable tolerable hazard rates.

The Contractor shall then undertake hazard control beginning with a causal analysis to allocate and determine the SIL levels for subsystems, equipment, and components. This process will allow identification of safety requirements for the System, subsystem, equipment, and components. These safety requirements shall be included in the overall requirements management process of Section 4.1.1, verified as fulfilled by the process of Section 24 (subject to the oversight and independence requirements of the Safety Management Process herein), and also be documented for the Safety Case either as a separate safety requirements specification or a subset of the System requirements specification, as described above.

The Contractor shall endeavour to identify potential new hazards throughout the design, manufacture, and verification processes. Any such hazards shall be entered into the Hazard Log, assessed, allocated, and entered to the safety requirements specification and verification process. Discussion of new hazards at the safety reviews is recommended.

7.1.7 Technical Safety Report

The Contractor shall generate a Technical Safety Report as Part 4 of the Safety Case. The Technical Safety Report shall show adequate evidence of functional and technical safety.

The Technical Safety Report shall have the following structure:

- Part 1 Introduction
- Part 2 Assurance of correct functional operation
- Part 3 Effect of Faults
- Part 4 Operation with external influences
- Part 5 Safety-related application conditions
- Part 6 Safety qualification tests.

The introduction shall provide an overview description of the design as required to facilitate a summary of the technical safety principles relied upon by the Contractor. The introduction shall also indicate the international, national, and local standards that the Contractor used as the basis for the technical safety of the design, including the release version of each. Any use of earlier versions of standards shall be justified.

Part 2, normal operation, shall contain all the evidence necessary to demonstrate correct operation of the System, subsystems, equipment, and components under normal conditions with no faults, in accordance with the specified operational and safety requirements. To that end the following aspects shall be included:

- System architecture description
- Definition of interfaces
- Evidence of compliance to all System requirements
- Evidence of compliance to all safety requirements
- Assurance of correct functionality.

Part 3, operation with failures, shall demonstrate that the System continues to meet its specified safety requirements, including the quantified safety target, in the event of random faults, and demonstrate which technical measures have been taken to reduce the risk of a systematic fault to an acceptable level.

This part shall also include demonstration that faults in any subsystem, equipment, or component having a Safety Integrity Level lower than that of the overall System, including Level 0, cannot reduce the safety of the overall System.

The following headings shall be used in this section:

- Effects of single faults
- Independence of items
- Detection of single faults
- Action following detection (including retention of safe state)
- Effects of multiple faults
- Defence against systematic faults.

Part 4, operation with external influences, demonstrates that the System will continue to fulfil the operational and safety requirements (including in fault conditions) when subjected to the external influences defined in this System Requirements Specification. The methods used to withstand the specified external influences shall be explained and justified.

Part 5, safety-related application conditions, shall specify or reference the rules, conditions and constraints which shall be observed in the application of the System. This shall include the application conditions contained in the Safety Case of any related subsystem or equipment.

Part 6, safety qualification tests, shall contain evidence to demonstrate successful completion, under operational conditions, of the safety qualification tests as described in Section 24.2.9. Although the safety qualification tests are a subset of the verification tests, they require Safety Management Process oversight and extra documentation in the Technical Safety Report part of the Safety Case.

7.2 Security of the Operational Transit System

A prerequisite for the success of the System will be user perception of security while in the System, along with a high level of actual security. Security and safety have been assigned high priorities; neither shall be compromised. The goal shall be a level of security for users, employees and property which will meet those required by the Client and local and national law enforcement agencies, as applicable. A System Security Plan shall be prepared by the Contractor for security during construction, installation, and testing and commissioning of the project as per Section 7.3.2. A separate document shall also be prepared to address guidelines and requirements regarding security on the System during the O&M period.

The System shall be designed, constructed, operated, and maintained to avoid the occurrence of personal injury, property damage and loss, and service disruptions resulting from acts of crime, vandalism, or sabotage. The System shall satisfy the following as a minimum:

a) Prevention: system features to forestall breaches of security.
b) Remote visual and auditory surveillance of station facilities.
c) Barriers to unauthorized intrusion to non-public areas of the System.
d) Protective covers to avoid damage or loss.
e) Vandal-resistant materials.
f) A coordinated coded lock access plan and system.
g) Detection: System features to permit timely detection of criminal acts.

h) Intrusion detection alarms at station entrances (for use when the station is closed), equipment rooms, power substations, guideway access/egress points, the OMSF and CCF, administration offices, and other restricted access areas.
i) Passenger-activated alarms.
j) Emergency communications devices in each car and station.
k) Restoration: System features to enable rapid responses to security problems and restoration of normal service.
l) Ease of access for non-System emergency personnel and vehicles.
m) Emergency procedures training programs.
n) Maintenance procedures which minimize repair-in-place time.
o) Security training programs.
p) Cybersecurity

Security equipment shall provide audio and visual information and be located conspicuously with instructions for use. Security communications equipment shall be easy for all passengers to use, including MI&H. All security installations shall be tamper-resistant, with both wiring and equipment protected and monitored. Procedures and equipment shall be provided for periodic testing of security subsystems.

7.2.1 Surveillance, Alarms and Communications

Communications devices shall be provided to ensure rapid and effective coordination between central control and local emergency services staffs. There shall be a continuous 24-hour recording of all wireless voice communications, and all voice communication with CCO CCF personnel.

Intrusion alarms shall be provided to monitor security, including when the System is not operating. Points where unauthorized personnel might gain entry to restricted areas of the System shall be provided with intrusion detectors and alarms. Restricted areas shall be any areas where the public or unauthorized personnel are not permitted. Sensors to detect a person on the guideway are not required. Intrusion alarms shall be routed to the CCF where they shall result in an audible alarm that requires CCO acknowledgment, a visual alarm, and a recording containing an index number, location of the intrusion, time of the report of the alarm and time of the acknowledgement. Alarm coding schemes and equipment proposals shall be submitted by the Contractor for Client review during Security System Design Review.

The System shall include a closed-circuit television (CCTV) system with cameras installed to enable the CCO to monitor all station platforms and concourses. The Contractor shall ensure that adequate lighting exists at all times to permit clear, sharp CCTV images. The CCO shall be able to call up any CCTV camera image on a master monitor and record the signal from any camera on a video.

National standards for duration of record storage shall be applied for all communication information.

7.2.2 Power Substations

Entrance to enclosures and rooms containing power distribution equipment shall be:

- Provided with intrusion detectors and alarms that sound locally and send a signal to Central Control

- Posted with suitable warning signs that, as a minimum, meet applicable local codes
- Provided with a lock and secured from the public.

7.2.3 Wayside Facilities

Wayside enclosures shall be suitable for the environment in terms of dust, water, ice (with allowance for ventilation to the outside environment), protected by tamper-resistant covers and provide a degree of personal protection from incidental contact with the enclosed equipment. All electrical connections shall be vandal-resistant and shall be in vandal-resistant enclosures. Enclosures with safety-critical equipment shall have intrusion alarms that sound locally and send signals to central control.

7.2.4 Power and Communications

Power supply, telephone communications, CCTV, and electronic security lines entering central control, at each of the stations and power substations and along the guideway, shall be protected and located unobtrusively. All cables shall be in rigid conduit or suitably secured in cable trays.

7.2.5 Guideway

There shall not be access between the guideway and the ground or adjacent structures. Guideway access shall be permitted only at stations, designated points for maintenance access, and at emergency egress points. The Contractor shall identify any location where adjacent buildings, other structures, or roadways permit access to the guideway so that the Contractor and the Client can coordinate any necessary barriers or other solutions with others.

7.2.6 Restricted Access

The Contractor shall provide a key-type subsystem to control personnel access to fixed facilities, particularly restricted areas. These areas shall include station equipment rooms, wayside equipment rooms, power substations, guideway access/egress points, the OMSF, the CCF, and the administrative offices. Station entrances shall also be part of this subsystem. The subsystem shall include all keys and lock mechanisms required to regulate access to these areas. The keying function of each lock shall be changeable.

The keying subsystem shall have a hierarchical master key structure so that different areas and specific access points can be given different keys to limit access to authorized personnel and to permit authorized personnel access to different areas. Keys shall be of a high security type that is not readily duplicated. The key subsystem shall initially accommodate the System but shall be expandable to accommodate additional requirements of System extensions through the addition of additional sub-master key zones and appropriate keys.

As part of the System Security Plan, the Contractor shall develop a Lock Keying Plan. This plan shall include the design of the locks and keys, the master keying zone structure, the areas that will have locks, and the program to control key distribution and loss.

7.3 Safety and Security during Construction and Commissioning

A structured and systematic approach to safety and security shall be used during construction and commissioning so that potentially unsafe conditions are identified and controlled.

7.3.1 Safety during Construction and Commissioning

The Contractor shall identify and implement provisions for minimizing hazards to people and equipment during the field construction and testing period. During the field construction phase, the prime concern shall be in protecting employees and the neighboring community from the effects and hazards of the construction.

The relevant statutory health and safety regulations shall apply to the Contractor as well as to any subcontractor. The requirements for safety on site during the construction and testing stages prior to the commencement of Trial Running shall be determined from the Construction Safety Plan (which the Contractor shall supply) and shall not form part of the System Safety activities covered by the System Safety Plan.

At a minimum, the Construction Safety Plan shall include:

a) Providing sufficient manpower and plant to secure all work sites from unauthorized traffic.
b) Barricades segregating pedestrian traffic from work areas, where applicable.
c) Barricades segregating vehicular traffic from work areas, where applicable.
d) Securing work and storage areas.
e) Maintaining entries and exits for all buildings, parking lots, etc., where applicable.
f) Providing a system for monitoring dust and noise. The Contractor shall include in this system the means to control dust and noise to the level prescribed by applicable regulatory agencies.
g) Developing a traffic staging plan, if applicable, which effectively handles all traffic adjacent to and the through field construction areas. This includes detours, lane closures, and other similar methods to ensure smooth traffic flow.
h) Maintaining access and providing assistance as necessary to the fire brigade and fire-fighting facilities within the Project Site.
i) Conducting operations in coordination with affected utilities to avoid service disruption to subscribers.
j) Designating a responsible and qualified person(s) to act as a liaison with the community and authorities, and to take immediate corrective action to respond to valid complaints.

In addition to safeguarding the community, this effort shall provide for the protection of authorized personnel assigned to, as well as those who must occasionally pass through, the Work Site. Personnel covered by these provisions shall include employees of consultants, the Contractor, subcontractors, and utility workers.

The following provisions shall be incorporated in the Construction Safety Plan:

a) An introduction and safety evaluation program for new employees.
b) Mandatory pre-hire substance abuse testing program.
c) Regularly scheduled safety meetings with superintendents, foremen and other supervisory personnel, to discuss job safety and a continuing safety education program.
d) A tracking system which monitors the status of safety on the Project, which shall:

i) Provide a means for eliminating violations of OSHA and other applicable Governmental Rules, including immediate corrective action to be taken and long-term procedures to be developed to avoid further occurrence.
ii) Monitor equipment and provide or an ongoing inspection program.
iii) Monitor work methods and encourage programs for recognition of individual employee safety efforts and their contribution toward improved work methods.
iv) Provide a system for notification of emergency agencies in case of an accident.
v) Provide for the control of the necessary safety equipment, including employee protective equipment and fire-fighting equipment, and
vi) Provide the project with first aid stations and personnel experienced in first aid procedures.

7.3.2 Security during Construction and Commissioning

The installation site shall be operated, to the maximum extent possible, to avoid the occurrence of personal injury, property damage and loss, and work disruptions resulting from acts of crime, vandalism, or sabotage.

7.3.3 Potential mitigations for ensuring personal safety in the event of an incident

Regarding the potential mitigations listed below, which are necessary to ensure the safe stay and rescue of passengers, considering the defined residual risk acceptance limits, the potential mitigations that are

1. already in the existing chapters of the IMA Specification,
2. in the current ASCE 21-21 or GB/T 50458,
3. in the thematically relevant standards (If needed)

including the relevant chapters in each case. Personal safety may be ensured either by remaining in a safe area on board, taking shelter in place, or by (organized) evacuation.

A project-specific risk analysis is required, which may lead to one or more of the following potential mitigations for either a vehicle and or infrastructure. This appendix is intended to indicate how these mitigations can be fulfilled where appropriate. Other mitigations might be appropriate to address identified risks.

In addition to the potential mitigations for vehicle technology, the technical and operational function of the Operation Control Centre (OCC) is also essential.

The current potential mitigations are shown and, in case the existing regulations are not sufficient to assure personal and operation safety, guidelines were elaborated as a result of the risk analysis carried out on a system level. The concerns of passengers with disabilities and reduced mobility (PRM) were also taken into account.

The aim is to achieve planning certainty for upcoming projects so that the requirements for a risk assessment.

The generic requirement for personal and operational safety is met comprehensively, and the associated product liability of suppliers and the operator liability of the railway company can be demonstrably fulfilled.

The proposed details can be taken from the referenced documents to understand the specifications described below. This document lists all functional and systemic potential measures RX-X required for safe operation.

Based on the higher-level risk assessment, the respective safety requirement level (SAS) is defined for the necessary safety-related functions. These can only be deviated from if this is plausibly demonstrated to the neutral institution carrying out the assessment by means of a documented risk analysis (with reference to ASCE 21-13 Chapter 3.1 ‘SYSTEM SAFETY PROGRAM’ and in particular 3.1.2.1 ‘Hazard Analyses’ and Chapter 3.2 ‘SAFETY PRINCIPLES’).

8 System Dependability (RAM)

System dependability is a measure of the performance of a System and is typically quantified in terms of reliability, availability, and maintainability (RAM).

Intrinsic availability applies to subsystems such as a train or to components such as the brakes on a train. System availability applies to the System as a whole.

The System design shall incorporate reliability, maintainability, and availability (RAM) design requirements. These requirements shall reduce the probability of failures and the associated impact on passenger service. The Contractor shall select suitable design requirements to meet the required performance and may use techniques, including but not limited to, the following:

- Application of selected redundancy
- Use of components with proven reliability
- Minimization of single point failures which interrupt service
- Minimization of equipment operation stresses
- Provision of “operate-around-failure” capabilities.

8.1 Reliability

The reliability of a component, subsystem or the System as a whole is measured in terms of:

- Mean Time Between Failures (MTBF)
- Mean Time Between Service-Affecting Failures (MTBSAF).

The MTBSAF for the System is defined to be the cumulative number of Train Operating Hours (TOHs) divided by the cumulative number of Service Affecting Failures (SAFs). An SAF is defined as an event that causes a train stoppage exceeding three minutes (180 s) or as specified by client in duration. SAFs shall include:

- Unscheduled train stoppages
- Rerouting including trains not making scheduled station stops due to malfunctions
- Door malfunctions that prevent passengers from entering or exiting trains at stations
- Malfunctions that lead to potentially hazadous operations
- Operator errors.

The TOH will not include Level of Service (LOS) transition periods, which would normally not exceed 45 minutes.

Exclusions shall not be considered SAFs, and these shall include:

- Disruptions that cause train stoppages shorter than three minutes (180 s)
- Disruptions due to passenger-induced stoppages
- Disruptions caused by unauthorized intrusion into the System by persons, animals or objects unless caused by System malfunction or operator error
- Disruptions beyond the reasonable control of the Operator, including primary power failure
- Disruptions due to security problems, such as but not limited to vandalism

- Disruptions due to extreme weather or operations outside of the environmental design criteria
- Disruptions due to force majeure events
- Planned outages and stoppages including scheduled transitions between different LOS.

8.2 Availability

8.2.1 Intrinsic Availability

Intrinsic Availability = MTBF / (MTBF + MTTR) and is typically a subsystem metric.

8.2.2 System Availability

System Availability shall be defined and measured using the formula listed below:

A = MTBSAF / (MTBSAF + MTTRs)

Calculation of System Availability is typically based on a monthly average value. This definition is equivalent to the actual cumulative train operating hours (scheduled train operating hours minus the cumulative train downtime in hours) divided by the scheduled train operating hours.

Partial availability shall be granted for times when partial capacity is provided. The amount of availability granted shall be in proportion to the capacity provided with respect to the planned capacity.

Following an initial period of availability growth, the System shall achieve a System Availability of 99.0 % or better monthly. The availability growth shall be 97.5 % in a trial run prior to O&M, 98.0 % after 6 months O&M, 98.5 % after 12 months O&M and 99.0 % after 18 months O&M, all based on a 30-day moving average or as defined by client. The details of the availability measurement procedures and the availability growth period shall be defined in an Availability Demonstration Test Plan.

The predicted System Availability shall be provided for the System design phase. It shall be used to allocate MTBF, MTBSAF and MTTR values among subsystems and components.

This approach to System dependability follows CENELEC standard EN 50126 guidance.

The Contractor shall establish a RAM program plan and implement a RAM program in accordance with EN 50126. This shall establish an organization structure, responsibilities, procedures, activities, capabilities, and resources that together shall ensure that the RAM requirements are satisfied.

8.3 Maintainability

Maintainability is typically expressed in terms of:

- Mean Time to Repair (MTTR)
- Mean Time to Restore (MTTRs).

8.3.1 Mean Time to Repair

The Mean Time to Repair (MTTR) is the time required to remove a defective item, fix, or replace it, test, and restore the function back to an operational state. An MTTR activity may occur 1) in the field where there is a removal and replacement of a Line Replaceable Unit (LRU), or 2) in the repair shop as a second line maintenance effort on a subsystem LRU.

In line with common industry practice, the logistical time associated with the MTTR is not applicable.

8.3.2 Mean Time to Restore

The maintainability of the System as a whole is measured in terms of Mean Time to Restore (MTTRs).

The MTTRs for a System event shall be defined as the cumulative Time to Restore (TTR) Service after interruptions of Service (from the start of the stoppage or delay for any stoppage or delay more than 180 s), divided by the cumulative number of Service interruptions. The exclusions listed in Section 8.1 above shall also apply to Maintainability. The corrective measures for restoring Service may include:

- Automatic re-initialization (possibly including intervention by the CCO)
- Manual intervention (e.g. by field staff)
- Repair or replacement.

In the calculation of accumulated TTRs, only failures with downtime that is greater than 180 s shall be included. However, the TTR of each event will correspond to the downtime from the moment of detection until the moment of restoration of Service, either of the train or specific equipment that has malfunctioned or its replacement. Restoration is considered to have been achieved when the headway has been restored to within 1.75 times the scheduled headway then in effect (i.e., train service equilibrium).

Logistical time is considered entirely applicable in the context of System service restoration.

9 Vehicle

The System shall utilize straddle monorail vehicles per Section 3.5.5. These trains shall be capable of the performance required for the System to meet the key System operating parameters specified in Section 3.5.2.

Train configuration shall comply with Section 3.5.4.Station Boarding and Alighting Requirements

9.1 Dynamic Envelope

The vehicle and train dynamic envelope(s) shall be calculated by the Contractor assuming worst-case conditions including, but not limited to, combinations of secondary suspension system failure, flat tires, tread wear, guideway running and guidance equipment tolerances, maintenance conditions, guideway super-elevation, and vehicle/train overhangs and chording in curves.

The worst-case vehicle dynamic envelope at any location along the guideway shall be used to calculate the clearance requirements in Section 16.

9.2 Vehicle Space and Weight Allocations

Vehicle space and weight allocations shall be as follows:

- Passenger weight shall be taken as 65 kg per passenger
- A minimum area of 0.34 m^2 shall be provided for each seated position
- Minimum width of each seat shall be 450 mm
- Each wheelchair space shall have a minimum area of 0.93 m^2 as defined in Section 9.6.4. Standing passengers shall be based on the following densities (defined below).

Vehicle weight definitions are:

a) AW0: The weight of an empty vehicle.

b) AW1: The weight of an empty vehicle with all seats occupied and no standees.

c) AW2: The weight of the vehicle at normal capacity. This shall be computed by assuming all seats are occupied and with standees at a density of 6 m^2 in the remaining area in the vehicle available to standees.

d) AW3: The weight of the vehicle at crush capacity. This shall be computed by assuming all seats are occupied and with standees at a density of 8 m^2 in the remaining floor space in the vehicle available to standees.

e) AW4: The weight of the vehicle used for structural design purposes. This capacity shall be computed by assuming all seats are occupied and with standees at a density of 10 m^2 in the remaining area in the vehicle available to standees.

9.3 Vehicle Capacity

The normal, or design, capacity of a vehicle shall be determined based on AW2, with definitions of space and weight specified in Section 9.2, except where otherwise noted. Seats may be located over equipment cabinets or other areas that would not normally be available for standing passengers. Seating shall be provided for at least 12% of the passengers at AW2.

9.4 Vehicle Structure

This Section defines the structural requirements for the vehicle. Prior to beginning fabrication, the Contractor shall develop a set of criteria to be used for the design of the vehicle structure. The Contractor shall perform a structural analysis of the vehicle, including the carbody and underframe as well as suspension/guidance elements, to demonstrate that the design follows the buff strength and overriding requirements of EN 12663 P-IV or P-V. The appropriate class shall be selected based on the maximum train weight in operation in the system. The Contractor shall perform all necessary testing to verify the vehicle meets the structural requirements as part of the testing required under Section 23. No destructive testing is required.

9.4.1 Design Criteria

The Contractor shall develop the detailed structural design criteria for the vehicle. The requirements of EN 12663 P-IV or P-V as appropriate and Section 9.4, shall be used for vehicle related structural design. The following general criteria shall be used as the minimum basis for review of the structural design:

A. Loads for the frame, coupler link, trucks/bogies and major suspension/guidance members. These shall be defined as either working loads (normal loads expected in Service, AW2) or limit loads (worst-case loads expected in Service, AW3).

B. The safety factor applied to these loads shall be identified as being with respect to yield strength, ultimate strength, or endurance limits.

C. Additional safety factor(s) shall be applied to castings and welds.

D. Additional safety factor(s) as required shall be applied to any part; the failure of which could result in an unsafe condition.

E. The torsional and flexural deflection of the vehicle frame under load and how these criteria are to be verified.

The Contractor shall establish specific limits and numeric values for the general structural design criteria identified above. The following are minimum requirements for the vehicles:

1. Carbody Structure: EN 12663 P-IV or P-V as appropriate. The carbody structure shall be designed and tested to withstand AW4 static loading conditions in combination with a longitudinal buff load equal to three times AW0 weight, without permanent deformation.
2. Vehicle Connections: Inter-car mechanical connections shall withstand tensile and compressive forces that are equal to or greater than both the vehicle’s buff strength and the maximum loads which the vehicle may experience in service, normal maintenance, and storage facility operations. These connections shall be designed so that no combination of vehicle deflections, including suspension failure, flat tires, and guideway geometry, shall cause the connection to bind or result in stresses that will damage the connection or the vehicle.
3. Bogies and Suspension Elements: bogies/trucks and/or any structural elements that support the wheels and suspension shall be in accordance with EN 15827.
4. Deformation: The structure shall support all loads that are likely to occur during operations, without detrimental deformation. Any deformation occurring under System operating loads shall not interfere with safety.

5. Seats: The seat shall be of sufficient strength for the service intended. A single seat, including attachments to the vehicle body, shall be capable of withstanding the following loads:
    i. 1,766 N (180 kg) per passenger vertical downward at the centre of each seat bottom, with permanent set not to exceed 3 mm
    ii. 1,766 N (180 kg) per passenger vertical downward on the front edge, at the centerline of each seat, with permanent set not to exceed 3 mm
    iii. 1,766 N (180 kg) passenger vertical downward on the back of the seating surface, at the centerline of each seat, with permanent set not to exceed 3 mm.
6. Doors: The doors and supporting tracks and/or linkages shall withstand a static force of 113 kg applied at right angles to and approximately at the centre of the door panel and distributed over an area approximately 100 mm by 100 mm, without permanent deformation or permanent binding of the door mechanism.
7. Floor: The deflection anywhere on the floor shall not exceed a ratio of 1/800 times the span of the bogies on anormal plane with the vehicle loaded to AW2 and rigidly supported at the bogie/truck mounting points.
8. Roof: The roof shall support a 113 kg load acting over a 150 mm area at any location without permanent deformation.
9. Equipment: The Design Loads for all underfloor- and roof-mounted equipment, equipment boxes, equipment hangers, safety hangers, standby supports, and any parts of the vehicle to which these items are attached, shall not be less than 5.0 g in the longitudinal direction, nor less than 2.0 g in either the vertical or lateral directions. These loads, applied separately, shall not result in stresses that exceed the guaranteed minimum yield strength of the material. The strength of a fastener or the local area of the fastened structure shall not be the limit of the load-carrying capacity of that structure.
10. Materials: Any structural material in which the yield strength exceeds 80 % of the tensile strength shall not be used unless it can be substantiated to have a proven record of successful use in a similar transit application.
11. Vibration: All structural body and panel natural frequencies shall be sufficiently different from primary excitation frequencies to preclude any damaging resonant vibrations at all speeds and power conditions, up to maximum design speed.

9.4.2 Structural Analysis

This Section defines the requirements for structural analysis by the Contractor based on the criteria established in accordance with Section 9.4.1.

The Contractor shall perform a structural analysis of the car/vehicle structure, body, suspension and guidance elements, underframe, and equipment supports. This analysis shall include the calculated stresses, allowable stresses, and safety margins for all structural elements under each of the specified loading conditions defined in the established structural design criteria. The safety margin is defined as the allowable stress divided by the calculated stress, including safety factors required by the structural design criteria, minus 1.00. The analysis shall consist of a combination of manual and/or computerized calculations and finite element analysis. Finite element analysis shall be used, at a minimum, for any complex structural element whose failure affects safety or availability. The analysis shall include at least the following:

A. Structural arrangements and layouts of the car/vehicle and bogie elements. Materials and sizes of structural elements and the method of fastening shall be defined.

B. Diagrams showing externally applied loads and boundary conditions. Where finite element analysis is used, diagrams showing the element and meshing in sufficient detail to support the analysis of the car/vehicle and bogie structures.

C. Documentation showing the properties of the materials used in the vehicle structure. This shall include at least the guaranteed minimum yield and ultimate strengths, elongation, Young's modulus, and allowable fatigue stress data for each material.

D. Detailed stress calculations, including calculation of the safety margin, for each structural element.

9.4.3 Tipping Stability

The Contractor shall analyze the tipping stability for the vehicle and the trains loaded to both AW0 and AW3 using the appropriate center of gravity location for each and demonstrate that the design meets the following requirements.

A. The vehicle/train shall be stable under the following side loading condition: centripetal load traveling at 120 percent of design speed through the System guideway curves, plus a dynamic load of 0.10 times the vehicle/train weight. An upward vertical inertia load of 0.1 g shall be included to account for dynamic effects of the suspension system.

B. The vehicle/train shall be stable under a side loading condition of a sustained or gusting side wind of 90 km/h maximum as experienced along the alignment, in addition to the loading conditions of A., above. The vehicle/train at AW 0 shall also be stable under a side loading condition of a sustained or gusting side wind of 120 km/h maximum applied against the elevated side of a vehicle/train moving at creep speed on the maximum super-elevated guideway.

C. The vehicle/train shall not be derailed, i.e., de-mated from running and guidance surfaces, except for the power collector, if struck by another vehicle/train of any length at a speed of up to 13 km/h anywhere on the guideway.

No vehicle/train-guideway friction effects shall be included in computing vehicle/train stability.

9.4.4 Jacking Pads and Hoists

Adequate attachment points for hoisting the vehicle with a crane, including any special slings or fixtures, shall be provided by the Contractor. Jacking pads shall be provided to facilitate jacking the chassis at all suspension tie-down points and the trucks/bogies, if necessary. Jacking points shall be provided to facilitate main wheel removal. It shall be possible to jack one end of a car at a time without separating cars to allow wheel removal.

9.4.5 Bolts, Nuts, Fasteners and Welding Standards

All structural fasteners shall be metric, at least equal in strength to ISO 898-1 grade 8.8. All welding shall be in accordance with relevant international standards.

Unless otherwise specified, all structural connections shall be designed and implemented so that the ultimate strength of a fastener or the local area of the fastened structure shall not be the limit of the load-carrying capacity of that structure. It shall be assumed in a group structural connection that one single fastener failure does not impact the strength of the connection.

Each removable bolt, screw, nut, pin, or other fastener shall incorporate a locking device, if it is:

A. Part of a major structural load path, including all suspension members and propulsion and braking force paths, or
B. Part of a sensor, detector, or antenna mounting, essential to control System operation, or
C. Part of an actuator or control linkage essential to vehicle control, or
D. Performing any other safety-related function, or
E. Part of the under-carriage equipment, which is susceptible to falling off the vehicle.

Self-locking nuts may be used to satisfy this requirement only if the Contractor provides data specifically demonstrating that such fasteners are suitable for the above applications.

The contractor shall provide sufficient design documents to prove the safety of all critical fastener connections.

9.5 Vehicle Design Life

The Contractor shall design the vehicle to operate for at least 30 years in Service (per Section 3.8) at the average number of vehicle-km per year to meet the operating performance of the System specified in Section 5 and in an operating duty cycle as specified in this System Performance Specification. The vehicle shall provide safe and reliable service during its entire design life. Normal deterioration due to causes such as corrosion and fatigue shall not degrade safety or performance of the body, chassis, and running gear.

Suspension, propulsion motors and controls, door operating mechanism and controls, heating, ventilation, and air conditioning (HVAC) equipment, and draft gear shall have a minimum design life as specified in Section 3.8. This equipment shall also operate for at least 5 years before a major overhaul.

Consumables, such as filters, tires, and brake linings, are excluded from this requirement. All car-borne wiring, conduit, and piping shall not require replacement during the design life of the vehicle.

9.6 Passenger Comfort

9.6.1 Heating, Ventilation and Air Conditioning (HVAC)

HVAC shall meet the following performance requirements including load calculations.

9.6.1.1 Air Conditioning

Each car shall have two equal and independent air conditioning systems having an aggregate cooling capacity equal to the maximum calculated cooling requirement for the car. EN14750 category B vehicle will be used as a design guideline for the interior temperature setting parameters based on the local ambient design condition. Ambient design conditions applicable to the system location. These conditions, including the solar radiation on the roof and on all opaque and glazed surfaces of the vehicle and the internal contributions from the AW2 passenger loading and all interior lighting, electric, and electronic equipment within each passenger compartment shall be used to determine cooling requirements. For this calculation, each occupant's sensible and latent heat shall be evaluated based on the EN14750 passenger heat emission graph relative to the designed interior temperature.

In case of any single point of failure, the system shall maintain at least 50 % in cooling capacity for the vehicle.

9.6.1.2 Ventilation

Positive ventilation of outside air during normal operating conditions shall be designed according to EN14750 at the AW2 loading.

In case of emergency where the vehicle relies on battery power, the supply air fans shall maintain to operate for at least 30 minutes, and the fresh air flow rate will be the same as normal operation.

9.6.1.3 Heating

Heating shall be provided by heating coils located within the unit if required. If additional heating is required, floor heating shall be provided. The system shall maintain vehicle interior conditions according to EN14750 category B vehicle with an outside ambient temperature equal to the climate zone where the system is located. Alternately in locations where no climate zone is identified, the 99 % Design Dry-Bulb temperature reported in the latest ASHRAE Fundamentals Volume for the Official Weather Observation Station closest to the System can be used.

9.6.1.4 Condensation and Humidity

The HVAC system shall minimize condensation on interior surfaces, including windows. The design humidity shall be limited to a maximum of 60 % in normal operation. Re-heat is permitted if required to limit the interior humidity.

9.6.1.5 Controls/Temperature Uniformity

A system shall be provided to control the interior temperature. The control set point, measured at the return air temperature probe, shall be according to EN14750 Category B for cooling and heating adjustable to a range of ±3° C. The temperature uniformity inside the vehicle will be designed according to EN14750 Category B for normal operation. An exception may be made when the vehicle doors are open at a station.

9.6.1.6 Temperature Variations

If the ambient temperatures encountered exceed the defined design values related to Section 9.6.1.1 above, the interior temperature will be permitted to rise degree for degree with the temperature more than the design values.

9.6.1.7 Air Flow and Diffusion

The air distribution system shall provide sufficient diffusion at the outlet or diffuser so that air mixing will prevent direct impingement of coil discharge temperature air onto occupants. The ducting shall be designed so that in case of one or two supply air fan failure(s), the entire length of the vehicle can still be ventilated with at least 50 % air flow rate. Air velocity within the vehicle will be designed according to EN14750 Category B.

9.6.1.8 Failure Operations

If the refrigerant circuits of both cooling systems fail, indicated by an inability to maintain interior temperatures, the ventilation systems shall continue blower operation.

In case of an APU inverter failure, the HVAC system shall be able to maintain 50 % cooling capacity which may be powered by other APU inverters on the train.

9.6.1.9 Smoke Detectors

A smoke detector shall be located in the car and linked to the HVAC system. In case smoke is detected, the fresh air damper shall be closed, and HVAC system shall be shut down.

9.6.1.10 Air Intakes

All fresh air intakes shall be located to minimize the intake of heat from vehicle HVAC or other equipment, fumes, and dust.

For the energy saving, the fresh air damper shall be adjustable to provide enough fresh air flow rate according to passenger loading to reduce power consumption.

9.6.1.11 Filters

The vehicle HVAC subsystem shall have appropriate air filters that shall remove dust and other undesirable particles, be easily removed for cleaning and replacement.

9.6.1.12 Refrigerant

The proposed refrigerant shall comply with all applicable Montreal Protocol regulations.

9.6.2 Interior Noise Level

Interior vehicle noise shall not exceed 75 dB (A) under the following conditions:

- Operating on open, level, tangent track
- During acceleration, cruise and braking
- At speeds up to 80 km/h
- With auxiliary equipment operating normally
- Measured 1.6 m above the floor in the centre of the vehicle
- In accordance with ISO 3381.

Interior vehicle noise shall not exceed 68 dB (A) under the following conditions:

- At rest on open track
- With auxiliary equipment operating normally
- Windows and doors closed
- Measured 1.6 m above the floor in the centre of the vehicle

- In accordance with ISO 3381.

The following standards also apply in the measurement and evaluation of interior noise:

- ISO 1231 Part VII - Quantities and Units of acoustics
- IEC 651 Precision Sound Level Meters.

If pure tones are suspected, a 1/3 octave band analysis shall be performed. A pure tone is defined to exist when one 1/3-octave band exceeds the arithmetic average of the two adjacent bands by 4 dB or more in the range of frequencies between 250 and 8,000 Hz. If an adjacent band contains a pure tone, the next closest band without a pure tone shall be used in its place. A noticeable pure tone shall be considered to exist when the 1/3-octave band containing the pure tone contributes more than 1 dB (A) to the overall dB (A) level.

The following standards also apply in the measurement and evaluation of interior noise:

- ISO 1231 Part VII - Quantities and Units of Acoustics
- IEC 651 Precision Sound Level Metres
- IEC 225 Octave, Half-Octave and Third Octave Band Filters intended for analysis of sound and vibration.

9.6.3 Vibration and Ride Comfort

Vehicle ride characteristics for maximum sustained acceleration and deceleration, maximum rate of change of acceleration (jerk) and ride quality shall satisfy the following:

9.6.3.1 Maximum Sustained Acceleration

For ride comfort the maximum sustained acceleration measured on the floor of the passenger compartment shall be as given in Table 9-1.

Table 9-1 Maximum Sustained Acceleration for Ride Comfort

Direction	Acceleration m/s^2	Acceleration g
Lateral	± 0.98	± 0.10
Vertical[1]	± 0.49	± 0.05
Longitudinal, Normal[2]	± 1.3	± 0.13
Longitudinal, Emergency[2]	± 3.1	± 0.32

1. With respect to a 1 g datum.
2. Including the effects of grade.

"Sustained", "Longitudinal", "Lateral", and “Vertical” shall be as defined in Section 2.1.

Lateral and Vertical acceleration values shall be obtained with a standard piezoelectric accelerometer with a frequency range of at least 0.1 – 80 Hz.

Longitudinal acceleration value shall be obtained with a standard accelerometer with a frequency range of at least 0.1 – 80 Hz, noting that this device reads acceleration along the Longitudinal (fore/aft) axis of the vehicle.

The maximum Longitudinal acceleration limit is a rate of change of velocity (dv/dt). All other acceleration and jerk limits also include the effect of grades.

9.6.3.2 Maximum Jerk

For ride comfort the "Jerk" shall be the rate of change of acceleration and the maximum values measured on the floor of the passenger compartment shall be as given in Table 9-2.

Table 9-2 Maximum Jerk for Ride Comfort

Direction	Jerk m/s^3	Jerk g/s
Lateral	± 0.59	± 0.06
Vertical	± 0.39	± 0.04
Longitudinal	± 0.98	± 0.10

Jerk limiting is usually required for normal longitudinal acceleration and braking. Longitudinal jerk during application and removal of emergency brakes shall not be controlled.

9.6.3.3 Ride Quality-Human Response

In addition to the maximum sustained acceleration requirements of Section 9.6.3.1, the following Human Response requirements shall be achieved.

Weighted RMS values of acceleration averaged over any single station to station trip shall not exceed the ISO 2631 (1997) one-hour whole body reduced comfort limits.

Ride quality shall be measured on one empty vehicle with no more than three (3) test/observation personnel and necessary equipment with a tri-axial accelerometer or equivalent system located on the geometric center of the floor and at one end of the car on the floor.

9.6.3.4 Vehicle-borne Component Vibrations

All carbody-mounted and Truck-mounted components shall be designed to have structural integrity and be operationally reliable over the life of the vehicle in the shock and vibration environment existing at the point of attachment of the component.

9.6.4 Mobility-Impaired and Handicapped (MI&H) Considerations

The vehicle and its interior shall, to the degree possible, include provisions to accommodate mobility-impaired and handicapped persons, in order not to impede these passengers from having accessibility to the System. Each end-vehicle in a train shall have at least one easily accessible seat assigned for priority seating for MI&H.

Additionally, each end-vehicle in a train shall provide a clear space to accommodate one wheelchair, near a door. The wheelchair parking area shall be free of vertical stanchions and other obstructions. Passengers shall be able to walk on and off the vehicle without being impeded by the wheelchair. Maneuvering room inside the car or compartment shall provide easy travel for a passenger in a wheelchair between the door and the designated wheelchair parking area. Over the full length of the wheelchair space the width shall be 700 mm from floor level to a minimum height of 1 450 mm with an additional 50 mm width to give clearance for hands on each side that is adjacent to any obstacle that will inhibit clearance for the wheelchair users hands (e.g. wall or structure) from a height of 400 mm to 800 mm above floor level (if one side of the wheelchair is adjacent to the aisle there is no additional 50 mm requirement for that side of the wheelchair as it is already free space).

National standards like ADA or CELEX 1300 (2014) to be recognized.

9.7 Propulsion and Braking Subsystems

A train of vehicles loaded to AW3 shall be capable of continuous operation at a speed of at least 80 km/h operating on level tangent guideway. The train shall be bi-directional, with equal propulsion and braking performance in either direction.

The brake system shall comply with the requirements of EN 13452-1 Mass Performance Requirements Transit Brake Systems for rubber-tired metros.

9.7.1 Propulsion/Braking Control

The propulsion and braking control system shall respond to signals from the ATC system or the manual recovery panel to adjust tractive effort, blend friction with electrical braking, and produce the tractive effort and braking necessary for smooth vehicle acceleration, deceleration, and cruising.

At AW3 load, on level tangent track, with zero wind speed, vehicles shall:

- Accelerate (average) at 1.0 to 1.1 m/s^2 from 5 km/h to 35km/h, subject to jerk limitations
- Reach 100 m from zero speed within 15 s
- Reach a speed of 80 km/h within 33 s.

The propulsion capability in a train shall not be reduced to less than 75 % by any single point failure.

The propulsion control system shall accelerate the vehicles to a maximum cruise speed at rates not to exceed the maximum longitudinal acceleration and jerk rates given in Section 9.6.3.

9.7.2 Duty Cycle

The thermal capacity of the propulsion and brake systems shall be based on the following two requirements:

Continuous operation of the train over the System guideway. Dwell time as established in Section 5.1.2. Headways shall be set for the maximum Line Capacity required in Section 5.1.7. The train shall be loaded to AW2. The maximum ambient temperature of Atmospheric and Weather-related shall be assumed and does not include local temperature changes due to vehicle or wayside equipment. Air conditioning and other accessories shall be operating.

One AW0-loaded train shall be able to safely push or pull another AW3-loaded inoperative, equal-length train into the most convenient station (permissible to recover in either direction), regardless of where it is located, and then push or pull the same vehicle with both vehicles empty (AW0) to the OMSF. The environmental and operating conditions of the paragraph above shall apply, except that degradation in speed, acceleration, and deceleration will be permitted.

9.7.3 Service Brakes

A service braking system shall be provided in accordance with EN 13452-1 Mass Transit Brake Systems Performance Requirement for rubber-tired metros. The minimum deceleration performance for vehicle weights up to AW3 shall be an equivalent deceleration 1.1 m/s^2 on level tangent track. The service braking system shall stop the vehicle within its required deceleration profile and provide jerk limiting for all vehicle speeds, loads up to AW3, grades, turn radii, and environmental conditions within the System's operating range. All failures of the service brake system or any portion of it shall be alarmed at the Control Center.

Service brakes shall use combined electro-dynamic electric motor braking and friction braking. A smooth transition from one braking mode to the other shall be provided to meet the acceleration and jerk requirements of Section 9.6.3.

During electro-dynamic braking, the electrical power generated shall be accepted solely by the System. Receptivity of regenerated power shall be guaranteed by other energy users and/or by wayside or vehicle-mounted resistors, or energy storage devices, to consume the regenerated energy, as per section 10.7.

The friction brakes shall have a capacity sufficient to supplement the electro-dynamic braking to achieve total train service brake deceleration requirements. The service brakes will normally supplement dynamic braking:

- For overloaded vehicles at speeds above normal dynamic braking limitations
- Towards the end of a service stop
- For failure management purposes, e.g. after partial loss of dynamic braking.

The service brake mode shall be fail-operational. Speed limitations are permitted if more than 25 % of dynamic braking is unavailable.

9.7.4 Emergency Brakes

Emergency braking rates shall meet the requirements of EN 13452-1 for rubber-tired metros, and as advised by this, up to AW3 passenger load. During any emergency stop, all emergency brakes shall be applied, providing a retarding rate of not less than an equivalent deceleration 1.5 m/s^2 at AW3 plus rotational mass equivalent on level, tangent guideway.

The emergency brakes shall be fail-safe. If a command is issued for them to be applied, they will remain applied until the train comes to a stop, even if the initiating command is removed. After the train has stopped, the emergency brakes may be reset for normal operation by a manual reset on the train by authorized personnel; additionally, the emergency brakes may be reset by a control signal to that train from the CCO, unless otherwise prohibited for specific situations by this System Performance Specification. If, when safe conditions exist and the train is allowed to move, a subsequent malfunction occurs, the emergency brake shall be applied as before.

The emergency brake controls shall be interlocked with the propulsion controls, to include removal of propulsion power during emergency braking, in a Fail-safe manner. The emergency brake may use components of the service braking system but shall operate properly without any guideway or propulsion system power and in accordance with the requirements for design stopping conditions as specified in Section 9.7.5. In addition, the emergency brake shall incorporate sufficient redundancy and capacity such that the safe train separation assurance requirements of Section 11.1.2 can be met under design stopping conditions as specified in Section 9.7.5. The design stopping conditions shall be met with the brakes on one Bogie of the train effectively failed or non-functional.

9.7.4.1 Heat Fade

The emergency braking system shall function without degradation for two (2) successive applications from the maximum speed with an AW3 load and without overheating whereby the ATP system shall not permit more than one (1) remote reset of the emergency brakes from the CCC. If the emergency braking system has any components in common with the service braking system, then the emergency braking system shall function without degradation after meeting all requirements for the service brake duty cycle as specified in Section 9.7.2.

9.7.4.2 Wet Fade

In wet condition with the highest nominal application force of the vehicle (highest pad force, maximum load = max. EB conditions) the mean coefficient of friction shall not vary more than ±20 % from the nominal value necessary for achieving the required deceleration defined in Section 9.7.4a.

Together with other possible variations, this shall be taken into consideration when defining the deceleration for the safe train separation assurance requirements in Section 11.1.2.

9.7.4.3 Contaminants

Contamination of the emergency braking system by any fluids or foreign substances in proximity to braking components that might reasonably enter through a leak or other single point failure shall not adversely affect the deceleration levels required for the safe train separation assurance requirements in Section 11.1.2.

9.7.5 Design Stopping Conditions

The function of achieving safe stopping shall achieve SIL 4. Safe design stopping distances for the System shall be developed analytically and the results provided to the Client for review at the ATC Design Review. Such computations shall include all worst-case time delays, train, and motor overspeed, and acceleration conditions. The effects of any grade shall be properly accounted for. An AW3-loaded vehicle shall be used. The safe stopping requirements shall comply with Section 9.7.4 and Section 11.1.2.

9.7.5.1 Guideway Conditions

Some considerations for safe stopping distance are guideway running surface friction (including roughness, wear, wet/cold), tire pressure and wear, and vehicle loading.

9.7.5.2 Out of Tolerance Conditions

The effect of out-of-tolerance conditions caused by brake lining wear, low air pressure, etc., shall be investigated by means appropriate for the particular brake subsystem to assure that proper parameters were used in the stopping analysis. Tolerances to be investigated shall include at least:

- Variations in brake lining coefficients of friction as manufactured and after operation
- Effects of wear on mechanical tolerances and clearances.
- Other characteristics that, while not representing a brake subsystem failure, could reasonably be expected to cause degraded System performance.

9.7.6 Parking Brakes

The parking brake function shall be provided by a mechanical friction parking brake. It shall be activated wherever the vehicle is stopped, including normal station stops.

The parking brake shall be capable of holding an AW3 loaded vehicle on the maximum grade without application of guideway or vehicle-borne power for an indefinite period.

The parking brake function may be provided by elements of the service and/or emergency brake equipment, provided that the requirements of Sections 9.7.3 and 9.7.4 applicable to that equipment are met.

9.8 Electrical Subsystems

The vehicle electrical subsystem shall comply with the following requirements. The Contractor shall co-ordinate the design of circuits and equipment to avoid damage or disturbance to operation caused by electrical noise and transients. Whenever possible, this shall be suppressed at the source. Circuits and equipment shall be designed and protected so that the sustained presence of any voltage from zero to the maximum, including the maximum regenerated, shall not cause damage to any part of the car or cause unsafe operation. Reduced power rail voltage is not expected during normal operation, but the vehicle shall be protected against such conditions. The Contractor shall be responsible for proper systems interrelation and function of the auxiliary power system. If any of the subsystems addressed in this section are implemented by wayside equipment instead of vehicle-borne equipment, the wayside equipment shall meet the same performance criteria as specified below.

9.8.1 Vehicle Primary Power Subsystem

Power for the vehicle shall be obtained from power rails on the guideway at 750 V DC and conditioned, as necessary, on the vehicle to the appropriate voltage for propulsion, auxiliary, and housekeeping functions. The vehicle’s primary power system shall also return power regenerated by the traction motors during braking cycles to the power rail system.

The power rail system shall be carried into the maintenance bays to power the vehicles during maintenance, as needed. The maintenance plan(s) shall consider the type of activity and the power requirements in relation to safety of personnel working around and, on the vehicles, and recommend under what situations and for which activities the power is to be removed from the power rails.

9.8.2 Power Collection

Vehicle power shall be obtained via the power collectors. Each vehicle shall be provided with power collectors that are compatible with the characteristics of the contact rail. The power collector shall function under the maximum expected excursions of the vehicle from wind loads, passenger loads, centrifugal loads, dynamic loads, and normal variations in tire pressure.

Power collector redundancy shall be provided on each vehicle in a train to ensure continued contact throughout the guideway. If one collector assembly is inoperable, the remaining collector assembly or assemblies shall be sized to carry the entire vehicle electrical load for an indefinite period.

A female electrical receptacle shall be provided on each vehicle. When connected to a male receptacle (stinger) in the depot workshop at 750 V DC, it will distribute power to propulsion and auxiliary equipment.

9.8.3 Auxiliary Power Subsystem

An auxiliary power subsystem shall be provided to supply power to various electrical devices on the vehicles that are not supplied directly at 750 V DC from the primary power supply. Auxiliary power shall be made available in each vehicle as follows:

- 380 V, 60 Hz, 3-phase ϕ ac, according to IEC 61287
- 230 V, 60 Hz, 1 single-phase AC
- DC power at 24V, 48V or 110 V DC.

Contactors and relays shall be transit or heavy industrial quality, successfully proven in transit service.

9.8.4 Convenience Outlets

The output of the auxiliary power inverter system shall locate two 230 V or 60 Hz, single-phase ac power outlets with a total capacity of 13 A, in every passenger vehicle. The 230 Volt outlets shall be a heavy industrial-type, grounded, duplexed convenience outlets, located in the passenger seating area, and mounted with tamper-resistant screws. Each outlet shall be protected against unauthorized use or vandalism by a tamper-resistant cover.

9.8.5 Emergency Power Subsystem

In the event of loss of primary vehicle power, an on-board battery emergency power subsystem shall assure uninterrupted continuation of the following functions for the greater time period of 30 minutes, or for a time period as determined by the analysis performed in accordance with Section 7.1.7.

- Public address and continuous two-way communications with Central Control
- Vehicle emergency lights of 9.8.8 and all vehicle exterior marker lights
- Any vehicle function required for disabled vehicle recovery
- Exterior marker lights and fault lights
- ATC system
- Alarm and malfunction reporting

- Ventilation of at least 140 LPM (litres per minute) per person at AW2 loading level.

Each vehicle shall have a means for keeping the emergency battery or batteries in a constant state of readiness and with an indicator showing the level of charge. All batteries on the vehicle shall be transit type and shall be properly encased and ventilated. A low battery charge condition alarm shall be indicated at Central Control.

9.8.6 Circuit Breakers and Interrupters

Circuit breakers shall be provided for all circuits to guard against overloads and faults and to isolate on-board electrical subsystems for purposes of maintenance and to protect equipment from damage due to circuit faults. Each breaker shall have a nameplate clearly and permanently marked with the name of the circuit it protects.

High voltage dc primary power circuits and high voltage ac auxiliary power circuits shall be protected by circuit breakers located outside of the passenger compartment.

9.8.7 Grounding

Each vehicle shall be always grounded by a non-fused grounding circuit. A minimum of two grounding brushes, each with sufficient current-carrying capacity to handle fault currents of the entire vehicle electrical subsystem, shall be always in contact with the grounding rail. With the vehicle operating at any location on the guideway of the System, including the maintenance and storage facility, and with only one ground brush contacting the grounding rail, the touch-potential requirements specified in Section 10.3 shall be met.

All metal parts inside and outside the vehicle, including equipment boxes and cabinets, panels, and test receptacles, which could be contacted by passengers or operating and maintenance personnel, shall not exceed this potential. The vehicle-station-guideway grounding shall satisfy the requirements of Section 10.3.

The vehicle body, frame, and structure shall not be used to carry current for any vehicle electrical circuit. A differential current sensing means shall be used to remove power from the vehicle in the event of a primary power or traction power ground fault on-board the vehicle.

A grounding strap shall bond each bogie/truck, or other primary suspension element frame to the vehicle body. Grounding straps shall also bond all sections of the body that might become electrically isolated. Components mounted on these primary suspension system elements shall be bonded to the frames of those elements. All electrical and electronic metal enclosures and all equipment that uses electrical power shall provide a low-impedance path from the enclosure/equipment to the vehicle structure. The bonding method shall produce a dc resistance of not more than 0.0025 Ω from the enclosure to the structure, and ac impedance of less than 0.015 Ω at 150 kHz or of a comparable level at higher frequencies.

Where feasible, bonding shall be direct metal-to-metal contact between the enclosure/equipment and vehicle structure. Otherwise, conductors of sufficient cross-section to carry lightning discharge current or fault current of the equipment shall be used and shall limit the voltage drop across the bond to be consistent with the worst-case voltage condition specified in Section 10.3.

Wire shielding shall be provided to protect against and/or suppress electrical noise induced by any electromagnetic or electrostatic coupling. The wire shields shall be carried through all applicable junction boxes. Circuits shall be categorized. Shields contained in one category shall not be interconnected with shields in another category. Shields on low-level signal leads shall not be interconnected with shields on high-level signal leads in the same category.

Each group of shields shall be carried through a connector pin or pins, or on terminal strips, which shall be in the immediate proximity of the categorized group of circuits. There shall be no loops due to interconnections of shields.

9.8.8 Lighting

Energy efficient lighting shall be supplied for the vehicle interior and exterior.

9.8.8.1 Interior

The interior passenger cabin lighting shall be arranged to blend with the vehicle aesthetics and interior decor. The lighting output shall be a warm white light. Passenger area lighting shall be overhead and shall run the length of the passenger cabin. However, it need not be installed in a gangway area. Lighting fixtures shall be secure, rattle-free and vandal resistant. Florescent tubes and other powered fixtures shall be inaccessible to passengers. Diffusers shall be shatterproof.

Non-emergency lighting operating with new equipment at the rated voltage shall provide a lighting intensity not less than 375 lux between 800 mm and 1,600 mm above floor level at an angle of 45°. It shall not be less than 215 lux at floor level in the centre of the vehicle. The lighting design shall minimize glare. The door areas shall provide sufficient light on station platform areas within 0.6 m of the doors when they are open.

Emergency lighting powered by the vehicle battery shall provide a minimum intensity of 50 lux throughout the vehicle when the primary power source is not available.

There shall be no degradation in the above specified lighting levels for the design life of the vehicle, specified in Section 3.8, assuming lamp replacement for burn-out only.

It shall be possible for authorized personnel, only, to turn off interior lights selectively from inside the vehicle to improve visibility for manual recovery operations at night, especially to eliminate any reflections and glare on the windows. The vehicle shall have a lighting dimming feature to improve passenger visibility at night.

9.8.8.2 Exterior

The front and rear of each train shall be readily identifiable using marker lights that are always visible during operations. For manual recovery operations, these marker lights or separate headlights shall provide sufficient illumination for forward visibility of at least 5 lux at 10 m.

9.9 Suspension and Guidance Subsystems

The vehicle suspension and guidance subsystems shall meet the strength, fatigue life and ride comfort requirements specified in this Specification. They will be suitable for operation at the maximum design speed plus 10 %. Components mounted on any Bogie or similar suspension, or guidance elements shall be designed to withstand the stresses inherent in their location and attachment. The vehicle suspension and guidance subsystems shall provide positive mechanical methods for retaining the vehicle in the lateral direction. The vehicle shall be stable against tipping for all operating and environment conditions. See Sections 5, and 6.

9.9.1 Tire failure

Tire failure in load or guide tires shall not result in a condition that causes damage to the vehicle or infrastructure, is unsafe for passengers or prevents safe removal of a train from operation and return to the maintenance facility. A Tire failure detection system shall be provided capable of providing warning for all load & Guide tires. Alert should lead to the train being capable of reaching at least the next station. Then passengers should be released, and the train must be capable of returning to the workshop at limited speed.

9.9.2 Tire Life

The tire life is impacted mainly by track geometry, vehicle dynamics and operational conditions. They contribute significantly to the operation and maintenance costs and are therefor part of the Total cost of ownership.

The contractor shall provide the process and methodology which is used to determine the tire life in the bid stage, as well as the optimisation once the system is in service. The contractor shall provide solid evidence of tire performance and its life cycle cost. The contractor shall provide a safety mileage limit based on carcass endurance as defined by the tire manufacturer at the beginning of each project, according to the specificities of the track and the characteristics of the vehicle.

9.9.3 Loss of Load Leveling

If load leveling is used to provide vertical alignment, unsafe vehicle tilting shall be prevented in the event of any failure.

9.9.4 Odometers

Each vehicle shall be equipped with an odometer for determining actual distance traveled. The odometer shall accumulate vehicle-km regardless of the direction of vehicle travel.

9.9.5 Vehicle Weight Overload

The Contractor may include a weight sensor to detect the weight of the vehicle if it is required to avoid unsafe operating conditions. However, such overload condition shall not be less than the AW3 vehicle load.

9.10 Doors

Automatic, power-operated, bi-parting, horizontally sliding doors shall be provided on both sides of the vehicle for passenger entrance and exit. There shall be a minimum of two sets of doors per side of each car. The number and width of doors shall meet the requirements of Features and Dimensions given the vehicle capacity calculated as per Sections 5.1.4, 5.1.7, 9.2 and 9.3.

9.10.1 Features and Dimensions

Passenger side door openings shall be sufficiently wide to enable passengers, including those in wheelchairs or with baggage, to enter and exit within design Station Dwell Times, as determined in Section 5.1.4.

A minimum functional clear doorway width of 1.3 m shall be provided. The minimum doorway height shall be 1.93 m.

The upper portion of each door panel shall contain a large safety glass window. There shall be a kick plate at floor level.

Doors shall be constructed to provide proper strength and rigidity to sustain without door release or permanent deformation, a force of 900 N, applied on an area 600 mm by 300 mm with the long axis parallel to that of the door 50 mm from the door edge and centred within the height of the door. Doors and associated equipment shall be able to withstand a +/- 5 g longitudinal shock without opening and subsequently be capable of being opened manually.

The door seals shall be designed to withstand the operational environment. They shall act as a barrier against externally generated noise and shall not be the cause of self-generated noise.

It shall not be possible to entrap fingers, hands or clothing between door panels and adjacent fixed Sections while doors are opening or closing. Door panels, operating mechanisms and linkages that could pinch or injure passengers shall not be accessible.

9.10.2 Door Operation and Control

The passenger doors shall be actuated under control of on-board microprocessor-based control equipment capable of performing diagnostics. They shall be controlled and monitored on a per car basis. The doors shall be synchronized with the operation of the platform doors in all modes of operation including normal, obstruction detection and out of service.

Door or door control subsystem failures shall not result in a vehicle door unlocking or opening when not commanded to do so and shall meet all requirements of Section 11.1.7. Door interlock requirements are discussed in Sections 11.1.8 and 11.1.9.

9.10.2.1 Door Operators

A door operator shall be accessible from the passenger compartment via a hinged, tamper-proof, and locked cover. The door panels shall remain open as long as the opening signal is present to the door operator. When the door close command is applied, the door panels shall close and latch into position as the closing cycle is completed.

The door opening time shall be adjustable between 2.5 and 4.0 s and the closing time between 2.5 and 4.0 s. Passengers shall be protected from injury by the obstruction detection feature of the door controls.

9.10.2.2 Obstruction Detection Feature

Each side door panel shall be fitted with a soft elastomeric door edge to provide a weather-tight seal and to avoid injury to passengers on closing. These edges shall allow small objects and items of clothing to be pulled through a closed door.

An obstruction detection feature shall be provided by appropriate programming of the microprocessor-based control equipment. Upon closing an obstruction of 25 mm diameter or greater located at any point along the leading edge shall result in both panels recycling. Door closing forces shall not exceed 133 N. If the obstruction detection feature is inoperative, the force required to prevent a door closing shall not exceed 133 N applied at a door leaf.

9.10.2.3 Door Status

Door status shall be indicated Vitally via trainlines to the on-board ATC system. Doors are monitored on a car train basis and closed status shall indicate that the doors are secured in the closed and locked position.

9.10.2.4 Door Recycling

After the designated Station Dwell Time, the on-board ATC system will issue the "doors close" signal. If the closing of the doors is obstructed, the effected doors only shall reopen and then attempt to close again up to a maximum of three iterations.

9.10.2.5 Audible and Visual Signals

An audible warning shall be provided for door opening and door closing. The tone and nature of the audible signal shall be dependent on the contract provisions.

Local door indicator lights shall flash to indicate that doors are closing.

Appropriate exterior lights shall be provided, one on each side of each vehicle that shall be activated at any time that the passenger doors are not closed and locked.

Local door indicator lights shall be activated when that door is not closed and locked.

9.10.2.6 Manual Operation

Side door operating switches shall be provided at the manual recovery panel. Separate "door open" switches shall be provided for the left hand and right hand doors. Visual signals to indicate "all doors closed and locked" status shall be provided at the manual recovery panel.

9.10.2.7 Crew Switch

It shall be possible to operate one door on each side of each end car of a fixed train unit with an interior and exterior crew switch. The exterior switch shall be accessible from a side platform or walkway. Both crew switches shall operate the door through the motor drive and safely override any door close commands on the trainlines. They shall be inactivated when the train is in motion. The switches shall be protected from the weather, inaccessible to passengers and tamper-proof.

9.10.2.8 Malfunction Provisions

Each side door shall be provided with a manually operated cut-out switch to disengage the door from its power source. Use of this device shall ensure that the door shall not operate and shall bypass the door status indicators to give a permanent door-closed indication for that door. The device shall be located inside the vehicles adjacent to the effected doors and shall not be accessible to passengers.

9.10.2.9 Emergency Release Feature

Each passenger door shall have a manually operated device that releases the door locking mechanisms. The force required to release shall not exceed 100 N. Actuation of the release mechanism shall cause a "door-not-closed and locked" status to be indicated. Once the device is operated, a push force of not more than 130 N applied to any point on the edge of one door panel shall open both panels. A manually opened door shall stay in any open position when the vehicle is stationary on grades up to 6.5%. Reset of the emergency handle and manual closing of the doors shall cause all locks to be reapplied and the release mechanism to be reset. The interior release device shall be accessible to passengers from inside the vehicle. The exterior emergency release mechanism shall be accessible by emergency personnel from the walkway and from side platforms for exterior operation. Doors shall be designed to be capable of being manually opened following an impact of 5 g on the door operator and door panels. The interior emergency release device shall be protected from vandalism by a frangible cover and shall include clear operating instructions either on or adjacent to the device.

9.10.2.10 Emergency Release Inhibit

When under ATP, an emergency release inhibit function shall safely prohibit the operation of the interior emergency release device on those doors which do not open onto a safe evacuation route.

9.10.3 Door Threshold Alignment

Under all vehicle load conditions up to AW2 and with allowances for wear, adjustment, and maintenance conditions, the vehicle door threshold shall be level with the platform floor so that the difference in elevation between the vehicle and station floors shall not exceed ± 50 mm in either direction.

The horizontal gap between the platform edge of the pedestrian surface and the vehicle floor, with the door open, shall be minimized and in no case be greater than 100 mm.

9.10.4 Emergency Exits

Each car shall be equipped with two or more emergency exits. At least one of these shall be a door that leads directly to a safe emergency egress route at any point in the System, regardless of train length. The second may be a window that leads to the emergency egress route. Emergency doors shall not impede passenger exiting. There shall always be at least one unblocked emergency exit from each passenger compartment at all locations along the guideway.

The opening of any emergency door, and/or regular passenger door used as an emergency door, shall be possible from inside and outside the vehicle by means of a mechanical latch that operates independently of any on-board power and the following requirements. The emergency door-operating mechanisms on the inside of the vehicle shall be conspicuously marked including simple operating instructions. These mechanisms and instructions shall be clearly visible under normal and emergency lighting conditions.

The interior emergency release door on the non-station side, non-walkway side, or cliff side of the vehicle shall be disabled during normal automated operation.

The emergency door and any such operable passenger door shall open onto the safe emergency egress route. The emergency door release inhibit mechanism shall fail in a manner that permits the emergency doors to open when operated. Such failure shall result in an alarm message to Central Control. Opening any emergency exit shall meet the requirements of Section 11.1.7.

9.11 Exterior Design

The exterior and body features shall allow easy cleaning, including washing. Body and windows shall be sealed to prevent ingress by dust or water under normal operating conditions and during cleaning by personnel or the car wash.

The Contractor may assume that the roof color will be white or a similar reflective color for vehicle HVAC design purposes. Logos and numbers shall be applied to the finished exterior and shall meet all durability and related requirements.

The Contractor shall submit color renderings for approval by the Client at the Preliminary Vehicle Design Review.

9.11.1 Passenger Module

The passenger module shall be designed for 30-year life with no corrosion considering proper maintenance. Proof of corrosion resistance appropriate to the climate shall be provided. All dissimilar metal components including fasteners shall be appropriately insulated from each other to avoid galvanic corrosion.

9.11.2 Finishing

The vehicle exterior shall be painted, completely or partially, to conform to the approved color scheme and design. Fiberglass need not be painted if the desired finish colors are an integral part of the gelcoat. Steel shall be primed and painted. Stainless steel shall be painted only as needed to meet aesthetic and thematic design requirements. Exterior aluminum surfaces shall be anodized or primed and painted.

9.12 Watertight Construction

Each car/vehicle, over its range of AW0 to AW3 loads and including doors and window seals, shall be watertight when exposed to water spray from a 275 kPa, 20 L/minute nozzle located 1.5 m from the exterior surface and directing the water perpendicular to the surface during factory tests. All vehicles shall be tested at AW0 load condition only. The entire vehicle, sides, ends, and roof shall be tested after a minimum soak time of ten (10) minutes. At least one water tightness test, as a qualification test, shall be performed on one vehicle before the installation of insulation and/or sound deadening material, and another shall be performed after all materials and equipment have been installed. Insulation that is integral with walls of a sandwich construction shall be permitted in both tests as long as tests include detection of any leaks and seepage at any holes in, and at the edges of, such wall material. A small amount of seepage will be permitted at the door seals; however, no water shall spray into the vehicles at the door seals. During the water tightness testing, water shall not enter or in any way impair the operation of any subsystem or equipment.

The vehicle shall incorporate a drip molding above the door openings. Wherever feasible, removable covers and access panels that require sealing shall use reusable seals and shall not require caulking or sealant. These covers and panels shall meet the water tightness test above with no leaking.

9.13 Interior Design

Vehicle interior dimensions shall accommodate the range of the 5th percentile of female population to the 95th percentile of male population. Minimum ceiling height shall be 2.1 m and minimum passageway height shall be 1.93 m. Refer to Section 9.6.4 for additional accessibility requirements. All standing passengers shall have access to vertical stanchions or handholds. Refer to Section 9.13.8. Window area shall emphasize a feeling of openness.

The interior shall have no sharp depressions or inaccessible areas and shall be easy to clean and maintain. Handholds, lights, air vents, armrests, and other interior fittings shall appear to be integral with the vehicle interior. There shall be no sharp, abrasive edges, corners, or surfaces.

Interior panels and partitions shall be permanently mounted by tamper-resistant and vandal-resistant fasteners or welded in place. Interior panels shall be attached so that there are no exposed edges or rough surfaces. Panels and fasteners shall not be removable by passengers. Use of moldings and small pieces of trim shall be minimized. Individual trim panels and parts shall be interchangeable to the maximum extent practicable.

As part of the Preliminary Vehicle Design Review, the Contractor shall submit a color rendering and other drawings showing general layout and the proposed interior design and color scheme for review and approval by the Client.

9.13.1 Interior Materials

Materials shall be selected based on ease of maintenance, durability, appearance, safety, and tactile qualities. Materials shall comply with the requirements of Section 9.14. Trim and attachment details shall be simple and unobtrusive. Interior panels and trim shall be secured, and all joints and fastenings treated, to avoid resonant vibration and/or noise generation.

Interior panel material shall permit easy removal of paint, greasy fingerprints, and ink from felt tip pens, etc. Materials shall be strong enough to resist everyday abuse and vandalism and shall be resistant to scratches and markings. Interior mullion trim, moldings, and trim strips shall match the adjacent panels/walls, except where they are specifically incorporated in the interior color scheme.

Flooring shall meet the requirements of Section 9.13.4. Seat materials shall meet the requirements of Section 9.13.5.

Samples of floor covering, seat, trim, panel, and stanchion/handhold materials shall be submitted to the Client for review and approval as part of the Preliminary Vehicle Design Review.

9.13.2 Access Panels

Access for maintenance and replacement of equipment shall be provided by panels and doors that appear to be as an integral part of the interior. All equipment compartments shall be locked to avoid unauthorized entry. Opening of all interior access panels shall require a special tool or key. Panel fasteners shall be standardized so that only one tool is required for special fasteners within the vehicle. Access doors for the door actuator compartments shall prevent entry of mechanism lubricants into the vehicle interior. All fasteners that retain access panels shall be captive in the cover. Removal of fixtures or equipment unrelated to the repair task to gain access shall be minimized. Access doors shall be hinged with props to hold the doors out of the technician’s way. Overhead access panels shall have safety catches to prevent the panel from dropping.

9.13.3 Fire Barriers

The passenger compartment shall be separated from the compartments containing the propulsion unit(s), propulsion control unit(s), and any propulsion-level-voltage powered auxiliary equipment. The partition between them shall be a fire barrier by incorporation of fire-resistant materials in its construction. These fire barriers shall retard propagation of any propulsion or propulsion control unit compartment fires into the passenger compartment and shall meet the requirements of NFPA 130 or EN 45455 for structural flooring.

Any penetration through the fire barrier for conduits, ducts, or any other reason shall meet the requirements of NFPA 130 or EN 45455.

9.13.4 Floor

The floor deck may be integral with the basic structure or mounted on the structure securely to prevent chafing or horizontal movement. Floor fasteners shall be secured and protected from corrosion for the service life of the vehicle. Floor coverings shall withstand a static load of at least 670 N applied through the flat end of a 13 mm-diameter rod without permanent visible deformation. Floors shall meet the structural requirements of Section 9.4.

The floor of the passenger cabin shall be preferred in a continuous flat plane. Door threshold plates shall be flush with the floor surface. The entire floor shall be covered with material that remains skid-resistant in all weather conditions.

Flooring shall be a typical transit floor covering material. Carpeting shall not be provided. Flooring material shall be installed to avoid edges from coming loose. The floor covering and transitions of floor material to thresholds shall be smooth and present no tripping hazards. Where the flooring meets the walls of the vehicle, the surface edges shall be blended and sealed to a cove moulding to avoid debris accumulation and to avoid penetration of moisture. Samples of floor covering material shall be submitted to the Client for review and approval as part of the Vehicle Design Review.

The floor, as assembled, including the sealer, attachments, and covering, shall be waterproof, non-hygroscopic, resistant to wet- and dry-rot, resistant to mold growth, and impervious to insects. Any access openings in the floor shall avoid entry of fumes, flames, and water into the vehicle interior.

9.13.5 Seats

Seats shall be of molded form and of material that is easily maintained and resistant to vandalism. Coloring shall be consistent throughout the seat material, with no visually exposed portion painted. In lieu of specific client requirements padded seat cushion and back inserts shall be provided and shall be a color compatible with the rest of the interior of the vehicle. The seat shall be contoured for individuality, lateral support, and maximum comfort and shall fit the framework to minimize exposed edges. Seat design, materials, and colors shall be submitted to the Client for approval as part of the Vehicle Design Review.

The passenger seat frame and its supporting structure shall be constructed and mounted so that clear space under the seat is allowed for wheelchair maneuvering room and ease of cleaning, except for those seats with equipment underneath.

The top of the horizontal seating area shall be between 400 – 500 mm above the vehicle floor. The width of each seat shall be no less than 450 mm. The seat back height shall be at least 380 mm measured from the top of the horizontal seating area where these two surfaces meet. Seat depth shall be at least 430 mm. The pitch between transverse seats shall be no less than 710 mm. There shall be no armrests between adjacent seats.

Seating material shall satisfy the requirements of Sections 9.4.1 and 9.14, and shall be shown to withstand normal service for a period of at least 5 years.

9.13.6 Windows

The window in front of the manual recovery operator's position at any end of a vehicle equipped with an on-board manual controller shall provide a field of view to permit safe manual recovery operation. During such manual recovery operation, the driver may:

1) remove failed vehicles from the main track to the sidings or maintenance service area,

2) maneuver vehicles in the maintenance and service area and elsewhere, and

3) perform similar tasks.

All windows shall be fixed in position, except as necessary to meet the emergency exit requirements. All windows shall be easily replaceable without disturbing adjacent windows. Flexing or vibration during operation shall not be apparent.

All windows shall minimize external glare as well as reflections from inside the vehicle. The window glazing shall be single pane and free of visual distortions. Windows shall be tinted a neutral color, complementary to the exterior design and colors. The visible light transmittance of all windows on the sides shall be 22 to 28 % and end windshields shall be not less than 70 %. Mirrored windows shall not be permitted.

All vehicle glazing shall meet suitable international standards as well as local codes as required. For example (EN 15152:2007(Main). Railway applications - Front windscreens for train cabs Standard for impact resistance etc. to be added. ISO 22752:2021. Railway applications — Bodyside windows for rolling stock)

9.13.7 Insulation

Any insulation material used between the inner and outer panels shall be fire-resistant as required by Section 9.14 and sealed to minimize entry of moisture and to avoid moisture retention in sufficient quantities to impair insulation properties. Insulation properties shall be unimpaired by vibration compacting or settling during the service life of the vehicle. The insulation material shall be non-hygroscopic, resistant to fungus and breeding of insects, and shall not absorb or retain oils.

The combination of inner and outer panels on the sides, roof, and ends of the vehicle and any material used between these panels shall provide a thermal and acoustic insulation sufficient to meet the interior temperature and noise requirements of Section 9.6.1 and 6.3.2 respectively. The vehicle body shall be thoroughly sealed so that drafts cannot be felt by the passengers during normal operations with the passenger doors closed.

9.13.8 Stanchions and Handrails

Any standing passengers at any location in the vehicle shall be able to easily reach a vertical stanchion, a horizontal handhold between vertical stanchions, or a handhold attached to a transverse seat back or to a wall. Handrails and stanchions shall be convenient in location, shape, and size for both the 95th percentile male and the 5th percentile female standee. Vertical stanchions shall be located throughout the vehicle interior but not where they obstruct aisles, doors, or wheelchair access or cause congestion near doors. Horizontal handholds shall not present a hazard to standing passengers.

Stanchions and handholds shall be of stainless-steel tubing with satin finish. They shall be able to support the forces of the maximum number of passengers expected with an AW3 loading under maximum emergency deceleration conditions. Any joints in the handrails or stanchions shall avoid vibration or passengers from moving or twisting them.

9.13.9 Passenger Information

Each car and passenger compartment shall have automatic on-board announcements (including acoustic) that identify each station as it is approached to inform passengers of the impending stop. Automatic announcements shall also identify the next station the vehicle is destined for after the vehicle departs a station. This subsystem shall have other appropriate messages related to passenger information and safety.

Static graphics shall be provided in each car for operational and emergency information. Each passenger compartment shall have at least one System route map approximately to scale and identifying all stations. Graphics shall indicate the normal exit doors, MI&H priority seating, and wheelchair position(s) and restraint use. Emergency instructions to passengers concerning use of fire extinguisher, the two-way communication system, emergency egress, and manual door opening controls shall be prominently displayed.

Graphical information shall be, to the maximum extent possible, self-evident pictorial representations that require minimal written instructions. Where words are necessary, graphics shall be appropriately legible. Other information, including prominent "no-smoking" and similar prohibition signs shall be provided. Interior graphics shall be subject to the review and approval of the Client as part of the Graphics Plan.

Each passenger compartment shall have standard provisions for advertising graphics where feasible along the top of the side and end walls.

Special consideration shall be given to the integration of blind or visually impaired passengers.

9.13.10 Video Surveillance

Vehicles shall be equipped with video surveillance equipment. Each car shall be equipped with two cameras located so as to provide coverage of the vehicle interior so that a person cannot be hidden from view. Images shall be recorded on board each train, and the recording media shall be removed or downloaded periodically for storage. Capacity shall be adequate to store not less than three days of recordings under normal operations. Cameras shall be of sufficient sensitivity to operate properly under all normal vehicle interior lighting conditions. Recording shall be at three frames per second under normal operating conditions but shall increase to 15 frames per second automatically upon the occurrence of selected events (intercom button pushed, fire extinguisher removed, and emergency door release activated). Failure of any camera power supply or recorder shall result in an alarm message in the Central Control Room.

9.13.11 On-board Passenger Information Display / Passenger Information

Two (2) passenger information display screens shall be provided per car. Display screens shall be mounted at each end of the car and shall feature suitable size, resolution, and performance characteristics for viewing within the car.

The on-board passenger information display system shall interface with the on-board vehicle PA system to receive passenger information triggers such as next station and terminus information. When triggers are received, the operational information shall be displayed on all display screens.

9.13.12 Resistance to Vandalism

Blind fasteners are preferred for fastening seatbacks, trim, and panels. Where blind fasteners cannot be used, tamper-proof fasteners shall be used. Walls and ceilings shall be graffiti-resistant.

9.14 Flammability and Smoke Emission

The materials used in the vehicles shall comply with NFPA 130 or EN 45455.

The Client is responsible to ensure that interior/exterior advertising, and any other equipment added to the vehicle that is not part of this contact, meets the flammability and smoke emission requirements of NFPA 130 or EN 45455.

9.15 Fire Protection

Each passenger compartment shall have smoke detectors which, when activated, shall annunciate a fire alarm in Central Control. See Sections 11.3.5 and 11.3.6. The detectors shall be appropriate for transit car application. Smoke detectors shall be located in the return air ducts of each air conditioner. There shall be a means to test the smoke detectors.

Each car shall have a fire extinguisher suitably located and secured in the car. Removal of the fire extinguisher from its designated position in the car shall annunciate a signal in Central Control. The information sent shall identify the train.

Thermal protection for electric motors shall be provided. This protection shall be provided by a separate overload device that is responsive to motor current.

9.16 Vehicle Coupling and Crashworthiness

It shall be possible to couple trains anywhere on the guideway to push or pull a failed train with an active train or the Maintenance and Recovery Vehicle (MRV).

9.16.1 Couplers and Drawbars

Couplers shall be provided on both ends of each train and the MRV to retrieve disabled trains and/or to move trains to and from storage.

Couplers shall be designed to support the recovery of fixed length trains at any point on the guideway. Manual intervention either from the wayside or from the manual operating panel is permitted. Transit grade couplers shall be fitted at the ends of fixed-length trains. If required for vehicle recovery purposes, an electrical head shall be an integral part of the coupler assembly so that limited trainline connections, sufficient for recovery, are automatically made when two trains are coupled.

Between the vehicles of a fixed train or consist (see Section 3.5.4), either drawbars or couplers are permitted. With drawbars, draft gear shall be used to carry drawbar loads to the vehicle chassis and electrical connections shall be made with jumper cables.

The energy-absorbing elements in the couplers and drawbars, together with other vehicle elements, shall be designed to meet the coupling and crashworthiness requirements in Section 9.16.2.

9.16.2 Vehicle Crashworthiness

The vehicle shall have a crashworthy design to reduce damage in the event of low-speed collisions and to protect the passenger compartment in the event of higher speed collisions.

The following crashworthiness requirements shall apply to maximum length trains loaded to AW3:

- Train to train coupling, with brakes applied on the stopped train, at speeds up to 5 km/h on level track, shall result in no damage
- Train to train collisions, with brakes applied on the stopped train, at speeds up to the manual recovery speed on level track, shall be limited to only cosmetic damage and replacement of energy absorbing elements. The primary structure shall remain intact with no deformation and the passenger compartment integrity shall be maintained. High voltage devices and associated connecting cables shall remain contained and shall not create electrical shock hazards to passengers or personnel
- Damage caused by collisions with end of line buffers shall be limited to only cosmetic damage and damage to repairable energy absorbing elements to the train, under conditions specified in Section 17.2.

Vehicles and buffers shall have an anti-climbing capability, to maintain alignment and engagement of the collision structure and to avoid overriding.

Maximum vehicle sustained accelerations during a collision shall not exceed 3.0 g.

9.17 Intercar Gangway

Unless otherwise excluded, an intercar gangway shall be provided between vehicles in a fixed length consist or train (see Section 3.5.4).

The unimpeded opening width of any gangway shall be a minimum of 765 mm (wheelchair access). Floor height variation within the gangway of up to 60 mm is permitted as long as appropriate space is available to avoid a steep slope and provided that the minimum clear ceiling height of 1,930 mm is maintained.

The gangway shall be enclosed and sealed to the environment including weather and noise. Moving parts on the gangway shall provide a safe environment for passengers at all times, including when the train is negotiating minimum radius horizontal and vertical curves.

The external profile of the gangway shall match the external vehicle width to preserve a clean, aesthetic look.

9.18 Vehicle Communications

On-board public address speakers shall be located in each vehicle to provide undistorted messages at a sound level of at least 5 dBA above the ambient noise levels of Section 9.6.2 everywhere in the passenger compartment. It shall be possible for maintenance personnel, but not passengers, to adjust the volume.

There shall be at least one (1) full-duplex communications device on each vehicle or passenger compartment. This device shall: 1) be clearly identifiable; 2) be vandal-resistant; 3) have a push-to-call button, a recessed speaker and microphone and no handset; and 4) have clear instructions integral with the cover plate or immediately next to it.

Other aspects of vehicle communications, including emergency intercom, public address, and automatic announcements, are discussed in Sections 9.13.9 and 12.1.

All voice communications exclusively within a train shall meet the intelligibility requirements of a recognized international standard.

The tests shall be repeated for a representative number of vehicles throughout the System to ensure that no areas of deficient audio intelligibility exist.

9.19 Vehicle Control

9.19.1 Automated Mode

The train shall be designed for automated operation satisfying the requirements of the ATC system defined in Section 11.

9.19.1.1 Manual Recovery Operations

A manual recovery mode of operation shall be incorporated as required by Section 5.3 for failure management and vehicle recovery operations only. In manual mode the speed is limited to a speed at which collision protection is provided.

9.19.1.2 Manual Recovery Control Panel

Controls for manual recovery operation of self-propelled trains shall be inaccessible to the public and be utilized from either end of a fixed length consist or train. An operator at either position shall have a field of view necessary to perform all manual recovery operations anywhere in the System and during all weather conditions specified in Section 60.

The control panels shall be activated by a different key than that used for access to the control panel and any other vehicle compartment or equipment cabinet. Each panel shall control all vehicles in a train and have at least braking and propulsion thrust level controls, a stop button to disable propulsion power and operate the emergency brakes, a speedometer, ATP aspect signal indicators, speed limits and alarms, door open and close, lighting, communications devices, and a key switch to activate/deactivate the panel. The propulsion shall have a "dead man" control to avoid train movement without positive manual actuation by the operator. If that control is released, emergency braking shall be immediately applied.

The door controls shall be suitably protected to avoid inadvertent door operating.

All on-board operating panels shall have a microphone and speaker that can be used for two-way, vehicle-to-CCC communications and to make announcements over the train public address system.

9.20 On-board Diagnostics

9.20.1 Malfunction Annunciation

An annunciator device shall be provided on each vehicle to indicate vehicle malfunctions. Each malfunction shall be uniquely indicated on an on-board/status panel or screen readily accessible (behind a lockable panel) to O&M personnel. Each indicator shall continue to annunciate the specific malfunction until the indicator is reset. For malfunctions that are remotely reset, the indications shall also be remotely reset at the same time.

Those malfunctions which are "manually reset only" shall have their indications also reset when the emergency brakes are reset.

9.20.2 Malfunction Classifications

The specific level of classification and report messages for vehicle faults shall be developed by the Contractor. It shall be sufficiently detailed to allow O&M personnel to make rational decisions in reacting to the malfunction reports.

10 Power Supply and Distribution System

10.1 General

The Power Supply and Distribution (PS&D) system shall:

- Interface with the local electric utility to receive and control medium voltage ac electrical power to substations within the System
- Supply and distribute power to the vehicles from traction substations through power rails and vehicle-borne power collectors
- Provide ac housekeeping power to passenger stations, the OMSF and the CCF
- Provide dc shop power for vehicle maintenance and testing
- Supply back-up power throughout the System
- Provide for power system and equipment grounding and protection.

10.2 Power System Performance Requirements

10.2.1 Power System Capacity

The power system shall be designed to support the peak and the continuous loads encountered during the normal start-up and operation of the Operating Fleet of AW3 loaded trains to provide the System capacity as defined in Section 5. The loads supported shall include all System electrical loads including on-board equipment as well as guideway-mounted equipment and all housekeeping loads at passenger stations, the OSMF and CCF.

10.2.2 Provision for Future Expansion

The power system shall be designed to facilitate System expansion as contemplated in Section 3.6.

10.2.3 Power System Redundancy

The power system shall be designed using equipment of established reliability and shall incorporate sufficient redundancy to achieve the Mean Time Between Service Affecting Failure (MTBSAF) requirements referenced in Section 8.

As a minimum, the power system shall be designed to support operations with any single substation out of service or any single electric utility feed out of service. Under these conditions, the power distribution system shall impose no restrictions on the operation of trains or of any auxiliary equipment and shall not result in any power loss of any section of the guide way (10.3).

10.2.4 Power System Protection and Grounding

The power distribution system shall incorporate suitable protective devices and grounding systems to mitigate the risk to passengers and operations and maintenance personnel from hazardous voltages or currents. In addition, the protective systems shall be designed to isolate faults and minimize equipment damage and interruptions to service.

10.2.4.1 Protection

The power system shall incorporate a properly coordinated and selective protection system to ensure that any power distribution system faults or overloads are detected and cleared rapidly without interrupting power unnecessarily to not-faulted sections of the power system. The dc feeder protective devices shall discriminate properly between fault currents and train starting/acceleration currents. Automatic reclosing shall be performed for momentary faults in the conductor rail system.

Rectifiers and dc switchgear shall be equipped with leakage detection systems with required safety and redundancy levels (chapter 7). The detection systems shall trip circuit breakers to isolate any equipment in which ground faults are detected.

The maximum anticipated short circuit current shall be determined at all switchgear busses and protective devices, and apparatus selected with short circuit ratings exceeding the available fault levels. Busbar, power cables, and other conductors in the traction power system shall be rated to withstand short circuit currents without damage for a time sufficient to allow protective devices to operate.

Measures shall be taken to ensure that all equipment is protected against transient overvoltage resulting from lightning, switching surges, or similar causes. These measures shall include:

- The proper coordination of insulation levels throughout the power distribution system
- The provision of a properly designed low impedance grounding system (see Sections 10.2.4, 10.3, and 22.4)
- The provision of lightning arresters at the high voltage terminals of power transformers fed from the local electric utility, and at substation feed points to the conductor rail
- Additional surge protection shall be provided for power system equipment as necessary. The connection of a surge arrestor to ground shall be dedicated, short, and straight.

The Contractor shall ensure that proper coordination is achieved between the protection of the System power supply and distribution subsystem and the local utility network.

The protection system shall be designed, constructed and installed in accordance with good engineering practice and with all applicable codes and standards. These shall include IEEE Standard 242 - Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems.

10.2.4.2 Grounding

The Contractor shall provide a grounding system for System equipment (including, but not limited to power distribution system equipment). Detailed requirements for grounding can be found in Section 22.4.

10.2.4.3 Cathodic Protection

A cathodic protection system shall be provided by the Contractor if necessary to protect guideway structures or nearby structures or buried pipes from stray current and other forms of corrosion. Such protection shall be supplied for any dc power distribution system, except that it will not be required if both the supply and return conductor rails are insulated from the guideway structure. Refer to Section 22.2 of this document for detailed requirements for stray current protection.

10.2.5 SCADA

The power system equipment shall include supervisory control and data acquisition (SCADA) equipment remote terminal units (RTUs) to allow remote control and monitoring of power distribution system equipment per Section 13.3.

Refer to Section 13 of this document for SCADA system requirements.

10.2.6 Power Factor

The System power factor shall be measured at the Utility bus to meet Utility requirements. This power factor shall be achieved for the System, including any passenger station loads included in the System. If the power system as supplied cannot achieve this power factor naturally, the Contractor shall supply power factor correction equipment as necessary to achieve it.

10.2.7 Harmonics

The power system shall be designed in accordance with IEEE Standard 519 Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems. Systems using dc distribution shall, use appropriate pulse rectifiers. If the power system incorporates power factor correction capacitor banks, these shall be designed to operate in the presence of the power system harmonics generated by the propulsion rectifiers and other converters in the System and detuned as necessary.

10.2.8 Proven Technology

The Contractor shall provide a power distribution system based on components that have been proven in similar transit service, applied according to recognized methods and good engineering practice, configured in an arrangement that has been demonstrated to provide the desired performance.

Where new technologies are to be introduced, the Contractor shall ensure that the validation program provides appropriate testing and validation methods to demonstrate suitability and compliance to all performance, reliability, availability, maintainability and safety requirements.

10.3 Power System Analysis

The Contractor shall perform simulations of System operation and the corresponding power system load flow analyses to demonstrate that the power system design will be capable of supporting the operations defined in this section. The analysis shall also show that the provisions for expansion will meet the requirements defined in this section. The adequacy of the ratings of all power cable, transformers, rectifiers, and switchgear shall be verified using the load flow analysis.

In addition, calculations shall be conducted to show:

- The expected System power factor
- The expected magnitudes of power system harmonics
- Short circuit analysis for the power system (ac and dc)
- Protection coordination calculations, including settings for all protective devices
- Grounding system analysis.

The Contractor shall include the analyses listed above in the appropriate design review packages. Preliminary versions shall be submitted at the PDR, and final versions at the FDR.

10.4 Power System Equipment Requirements

10.4.1 Switchgear

For each substation the Contractor shall provide dead front switchgear equipped for both local and remote control. The medium voltage level of the primary switchgear shall be agreed between the Contractor and the local power utility

Primary ac switchgear shall be equipped with electrically operated, draw-out circuit breakers. The circuit breakers shall be the three-pole vacuum type or SF6. It will be acceptable to use the following switching devices in the primary switchgear in lieu of circuit breakers, under the conditions stated below:

- Fused load-break switches for station service applications not requiring remote control can be motorized
- Manually- operated disconnect switches to isolate sections of the primary cable network, provided that overall protection is by circuit breakers.

For dc switchgear air-break, single pole circuit breakers.

Primary ac switchgear, and secondary dc switchgear, shall include the following features:

- Four positions: “connected”, “test”, “disconnected” and “removed”. It shall be possible to close the door of the breaker cubicle when the breaker is in any of these positions. Suitable safety interlocks shall be provided
- Interchangeability of circuit breakers of the same rating
- Capability for both remote control via SCADA with suitable interlocks, and local manual control, with remote/local selector switches and breaker open/closed indication
- Provision for padlocking with as many as three padlocks
- Copper busses
- Metering, to display the voltage of each bus and the current for each incoming or feeder unit
- Transducers, for remote indication of the metered quantities indicated above, plus incoming MW and MVAR for each substation.

10.4.2 Substation Transformers and Transformer-Rectifier Units

The transformers shall be natural-convection-cooled indoor dry-type, in sheet steel enclosures, complete with standard and specified accessories.

Liquid-filled transformers using silicone oil as a heat transfer medium may be considered for indoor use if acceptable to the local authorities.

The Contractor shall supply one or more transformer-rectifier units in each propulsion substation. The transformers shall comply with the requirements stated above and in addition:

- The design of the transformer shall take into account the special requirements of rectifier application, including the effects of harmonic currents and voltages
- The design of the transformer and its secondary connections shall be carefully integrated with the design of the rectifier.

Rectifier units shall be enclosed in sheet steel enclosures and shall use natural convection cooling. They shall be equipped with two-level temperature sensors providing both an alarm output to SCADA and a trip output to the primary switchgear.

Rectifier designs that incorporate fuses for isolation of failed diodes shall provide a means of monitoring the fuses for local indication and remote indication by SCADA. If the Contractor supplies a rectifier design that does not incorporate such fuses, it shall provide test reports or equivalent evidence to show that the design can withstand a diode fault without damage to any component and without rupturing the failed diode.

10.4.3 Conductor Rails

Power distribution to the vehicles shall be via rigid conductor rails mounted on the guideway. An overhead or catenary distribution system shall not be used. The rails and their mounting provisions shall be of sufficient strength to withstand all loads to be expected in service, including:

- Vehicle dynamic loads
- Compressive, tensile, or lateral loads due to thermal expansion and contraction
- Electromagnetic and thermal loads due to short circuits.

The conductor rail mounting provisions shall allow longitudinal movement to accommodate thermal expansion and contraction. The temperature range accommodated by the design shall include the temperature range noted in Section 6 with additional allowance for solar heating, I2R heating, and all other relevant factors.

Conductor rails shall be of aluminum and / or stainless steel. The conductor rail shall have a design life of not less than fifteen years when operated and maintained in accordance with the System operating plan. If aluminum and stainless steel are used together, the integrity of the method of bonding the stainless steel to the aluminum shall be demonstrated based on proven service or suitable tests. Materials other than aluminum / stainless steel will be considered if the Contractor can demonstrate that they provide equivalent performance and life expectancy.

Conductor rails shall be suitably insulated from each other and from the guideway structure. The insulators shall be designed to withstand:

- The mechanical and electromagnetic forces described above
- The thermal loading due to ambient air temperature, sunlight, and conductor rail losses under both normal loading and short circuit conditions
- Prolonged exposure to the local environment, particularly to sunlight and the associated ultraviolet radiation, dust and humidity.

The insulators shall have a design life of not less than fifteen years under these conditions.

The conductor rail system characteristics, and in particular the insulator characteristics shall conform to the requirements for stray current corrosion control defined in Section 22.2.

The conductor rail system shall be segmented with suitable switching means to allow isolation of sections of the guideway for fault isolation and maintenance purposes. The power zone boundaries thus created shall be chosen to correspond efficiently with the location of guideway crossovers, signaling equipment and propulsion substations.

10.4.4 Blue Light System

Blue Light stations shall be provided as specified in 3-1.5 of NFPA 130. They shall be located at all points of entry to the guideway to permit emergency trips and to assure that conductor rails are not energized in the vicinity of the Blue Light station.

The circuitry associated with the Blue Light system shall be configured so that once a Blue Light station is used to remove power from a guideway segment, the power will remain off until manually reset at the Blue Light station. It shall not be possible for a Central Control Operator or anyone else at a remote location to override or reset power turned off at these stations.

10.4.5 Power and Control Cable

Power cable applied for medium voltage, primary power shall be adequately insulated to meet local utility practices and shall incorporate insulation shielding. The cable shall have suitable jacketing material for physical protection and shall also be armored if it is installed in a location where it might be subject to physical damage. Armoring will not be required for cable installed in cable tray, conduit, or protected locations.

Power cable used for connections to the power rails shall have extra-flexible stranding and shall use a flexible insulation material. If required, the insulation may be covered with a layer of tough abrasion-resistant jacketing material.

Any power or control cable used indoors shall meet the smoke and toxicity requirements of NFPA 130, EN 45455 or UNIFE and any applicable local and national codes.

10.5 System Backup Power Supplies

The power system design shall include back-up power supplies for critical loads as detailed in Sections 10.5.1, 10.5.2 and 10.5.3.

10.5.1 Uninterruptible Power Supply Units

Uninterruptible Power Supply (UPS) devices designed and provided by the Contractor shall be in accordance with requirements of Section 10.6. The Contractor shall identify those System functions requiring UPS backup as part of the Power Distribution System Design Review, as defined in the FMECA.

UPS units shall be provided by the Contractor at the OSMF and CCF and at passenger stations as necessary to support, as a minimum, the following loads:

- The central control room and its associated computer equipment, communications equipment, displays, and lighting
- The automatic train control (ATC) subsystem, including the guideway switches.
- Emergency walkway lighting

- Communications subsystems throughout the System, including the fiber-optic data transmission system, radio, telephone, public address, CCTV, and SCADA
- The AFC system
- Passenger station emergency lighting and signage.

Separate UPS units shall be used to provide lighting and the other functions (ATC, AFC, SCADA and communications equipment).

UPS equipment shall be sized to provide power for all of the above functions for at least one (1) hour or longer if determined to be necessary by the analysis of Section 7.1.7. The UPS equipment shall provide alarm outputs to the SCADA system so that the operational status of the UPS equipment will be continuously monitored.

UPS status (e.g., on-line, by-pass, etc.) shall be indicated at Central Control. Changes in status, such as load on battery, load on auxiliary source, low battery, shall be alarmed and logged in accordance with Sections 11.3.5 and 11.3.6.

10.5.2 Substation Batteries

The Contractor shall provide a station-type battery and charging system for each electrical substation for protection, metering and control. The battery voltage shall be 110 V DC or as required by the TPS breakers. The battery capacity shall be sufficient to supply switchgear trip/close, protection, control and indication circuits for two hours after loss of auxiliary power. The substation battery charger shall be rated to carry the substation controls load and recharge a discharged battery in eight hours.

10.5.3 Emergency Propulsion Power Supply Units

There is no requirement for emergency or backup propulsion power.

10.6 Housekeeping Power

The Contractor shall supply, install, test and commission all of the equipment necessary to provide housekeeping power for the passenger stations, the OMSF /CCF, substations, equipment rooms, and all other System buildings and enclosures.

Housekeeping power shall be provided at the local standard voltage and frequency. Typically, outside of North America:

- Within range 380-415V, 50 or 60 Hz, 3ϕ AC
- Within range 220-240 V, 50 or 60 Hz, 1ϕ AC.

and in accordance with local or national codes.

10.7 Energy

10.7.1 Energy Planning and Design

A simulation of the performance of the proposed monorail transit System shall be run by the Contractor and results reported and interpreted in the proposal. The simulation results shall assist the Contractor and the Client in analyzing and adjusting the power system configuration to minimizing the energy consumption of the monorail System within the performance requirements.

The simulation shall address at least the following:

- Fleet performance
- Train speed profiles
- Power supply and distribution system load flows
- Train schedules
- Train routing.

A major focus shall be the disposition of energy during train deceleration, including:

- Regenerative braking
- Rheostatic braking, if any (energy dissipated on-board or on the wayside).
- On-board energy storage, if any
- Wayside energy storage, if any (using super-capacitors or otherwise).
- Automatic Assured Receptivity Units (wayside resistor banks), if any, and
- Returning energy to the utility, if any (with power factor correction and harmonic mitigation to meet Utility standards).

As a minimum, controlled electro-dynamic braking shall be available down to a speed of not more than 5 km/h. The electro-dynamic brake shall be regenerative and include rheostatic if necessary, with blending between these two modes. Regenerative braking shall have priority over rheostatic braking. Resistors for rheostatic braking may be located on trains or on the wayside, and clearly noted in the Contractor's proposal. In case of total failure of electro-dynamic braking, friction brakes shall be able to safely stop the train.

Recommendations for the adjusting of the power system configuration shall be included in the proposal addressing, in addition to the above, the location, rating and setting of traction power stations and energy storage or dissipation devices. Changes to a baseline power system configuration can be proposed if they are justified in terms of energy cost, O&M cost, capital cost and / or life cycle cost differentials or improved System performance.

10.7.2 Energy Consumption

Traction energy consumption shall be stated by the Contractor in the proposal. The stated value shall become a commitment in the contract for the successful Contractor. During the test and commissioning phase of the contract, the Contractor shall measure the traction energy consumption. If the measured value is more than 5% higher than the committed value, the Contractor shall be given time and opportunity to reduce measured value by adjusting the traction design or settings. The traction energy consumption commitment shall be based on the operation of one train on the guideway. During the bid phase, a simulation shall be performed based on specified scenarios and assumptions that are representative of the planned commercial operation of the System. Simulation results shall be included in the proposal together with the traction energy consumption commitment. In the testing and commissioning phase of the project, a test shall be conducted based on the same scenarios and assumptions as used in the simulation.

The traction energy consumption commitment and measurement shall be based on the following assumptions:

- The predicted energy consumption will be based on running one train on the guideway for one round trip. The train used in the simulation and the test will be of identical characteristics and passenger loading (using ballast of equivalent mass for the test)

- Operational parameters such as acceleration rates, maximum speed, deceleration rates, jerk rates, etc., shall be identical for the simulation and the test
- The guideway shall be predetermined using actual alignment data and shall be identical in the simulation and the test
- Details of the train operation shall be technology-specific to meet the operation requirement in Section 3.5
- Energy consumption shall be based on traction only; no auxiliary load will be considered
- If, for any reason, the alignment is significantly changed during the project phase, the Contractor shall be allowed to update the simulation results based on the new information, using identical simulation methodology as for the original prediction. The new energy consumption simulation results shall be used as the basis for test comparisons
- Energy consumption shall be expressed in kWh/pass km
- Average passenger weight shall be 65 kg
- Two vehicle loading scenarios shall be considered; one will be based on the maximum passenger load during peak operation, and the second based on the load during off-peak (i.e. AW3 and AW2)
- Two energy receptivity scenarios shall be considered, 0 % receptivity as well as 100 % receptivity.

For the simulation, the following assumptions shall also apply:

- Alignment data shall be based on System Alignment and Appendix 2 Tabular Alignment Data Train operation information shall be defined clearly in the proposal and consistent with this, especially the operating requirements in Section 3.5
- The simulator used to perform the analysis shall be validated and tested on other systems
- Train simulation data shall be based on the train resistance formula, tractive effort/braking effort vs. speed curves, propulsion efficiency curves, train tare weight, and other similar parameters
- For the test, the following assumptions shall also apply:
- Trains shall be run in Automatic Train Control (ATC), so the acceleration/deceleration rates, maximum speed, speed restrictions, dwell times, etc. are controlled and identical to the assumptions in the simulation
- The voltage and current shall be measured at the train traction equipment
- Energy consumption for 0 % receptivity as well as 100 % receptivity shall be measured. In other words, the power profile of train shall be monitored and recorded.

11 Automatic Train Control (ATC)

The ATC system shall comply with the requirements of IEEE STD 1474.1 CBTC Performance and Functional Requirements. It shall automatically regulate the movement of all trains, except those in Recovery Manual Mode (RMM), that is, on-board manual control without ATC supervision. The ATC system shall control train separation, routing, operating speed, maximum speed, accurate stopping, travel direction, door operation, longitudinal acceleration and jerk and safety interlocks. The ATC system shall also monitor the System operations.

The Automatic Train Control system (ATC) includes the following subsystems:

- Automatic Train Protection (ATP)

The ATP subsystem maintains safety of operation including safe train separation and safe switch interlocking management. ATP includes both wayside and train-mounted Vital safety functions.

- Automatic Train Operation (ATO)

The ATO subsystem controls the normal train operating functions including longitudinal motion control in accordance with station stops, track characteristics such as gradient and curvature, and the status of the line ahead.

- Automatic Train Supervision (ATS)

The ATS subsystem directs train operations, to provide regulated service under normal conditions and the best service possible under abnormal conditions.

Each ATC subsystem may be located on-board trains and / or on the wayside.

Each subsystem shall provide a link between the Central Control Operator and the System, providing all pertinent information about the System, including management data acquisition and reporting, and a means for the Central Control Operator to control various functions of the System

The Operating Modes shall comprise:

- Unattended Train Operation (UTO), UITP GoA4
- Recovery Manual Mode (RMM)

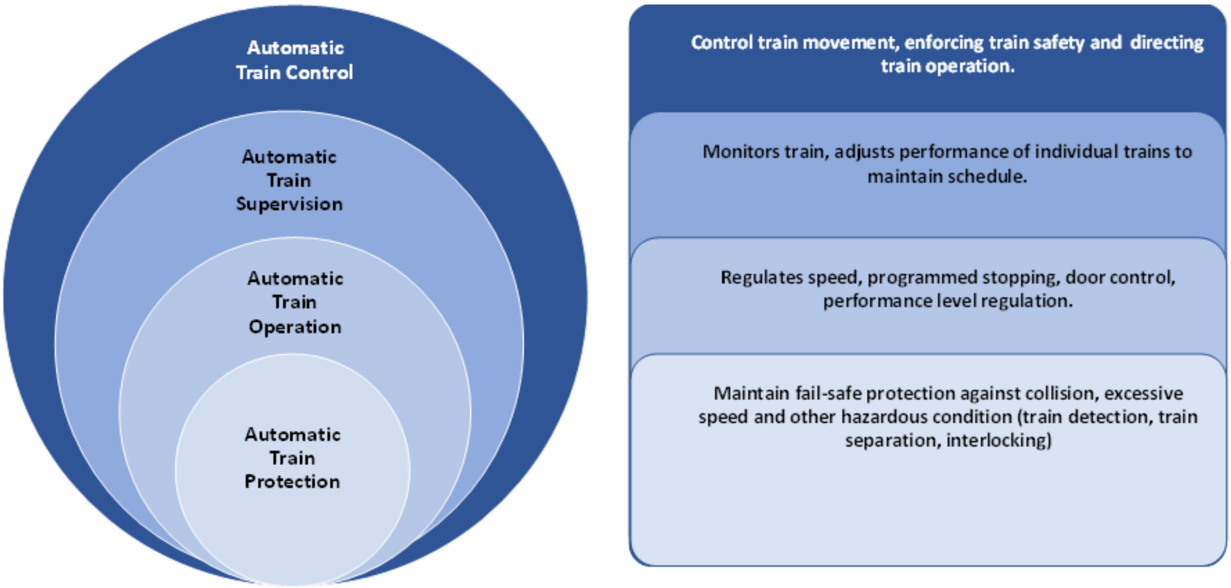

Figure 11-1: Automatic control IEE 1474

11.1 Automatic Train Protection (ATP)

The ATP subsystem shall provide for safe operation for individual vehicles and all operating train consists and shall perform the following operating functions, the requirements for which are given in subsequent subsections, as applicable:

a) Train location.
b) Safe train separation assurance.
c) Unauthorized motion prevention.
d) Overspeed protection.
e) Parted Train.
f) Signal transmission and detection.
g) Unexpected door opening protection.
h) Vehicle/station and door alignment interlocks.
i) Departure interlocks.
j) Reverse operation interlocking.
k) Route interlocking.
l) Service brake failure protection.
m) Speed measurement and zero speed detection.
n) End of track protection.
o) Facility door detection and response.
p) Obstructed motion protection.
q) Switch interlocking, safe switch mechanisms and safe switch principles, and

r) Safe resumption of service after power and/or ATC outages.

The safety provided by the ATP subsystem shall exist under all circumstances of guideway power, vehicle power, automatic operations, and with malfunctions in the ATP subsystem itself. Should the ATP subsystem become inoperable, no unsafe condition shall result. The ATP subsystem shall react appropriately, in a safe manner, whether an indication to the Central Control Facility is provided or not and react to an indication regardless of whether the failure has actually occurred or not. If the ATP subsystem fails, all automatic train operations shall cease immediately in the affected area, and all affected trains shall brake safely to a stop.

11.1.1 Train Location

The ATC shall determine the location of all passenger vehicles/trains. Train location shall be provided throughout the entire automated portion of the System, including any boundaries between automated and manual territories in the OMSF and elsewhere.

To establish train location and initialize the capability for ATO, trains shall be driven in areas with temporary protection, established from Central Control.

In the event that a train with its location established experiences a loss of location due to multiple failures, it shall be necessary to drive the train in Recovery Manual Mode (RMM) either to reacquire its location or to remove the train from automatic territory. These maneuvers shall be carried out under temporary protection established from Central Control.

Once train location is established or re-established, the train icon shall automatically be displayed and updated on display screens at Central Control.

11.1.2 Safe Train Separation Assurance

The ATP shall maintain safe separation between trains, in the same or opposing travel directions, and between trains and switch conflicts, and between trains and end-of-track termini. ATO speed regulation control shall affect normal service braking so as to prevent encroachment into an area of guideway reserved or occupied by another train. In the event that the ATO control fails or otherwise allows encroachment, the ATP subsystem shall enforce safe train separation assurance. If conditions are no longer considered unsafe, the EB (emergency brake) shall be resettable from the Central Control.

The method of imposing safe train separation shall allow for a smooth transition of train speeds from the maximum ATC authorized speed to zero speed.

The Contractor shall employ the safe braking model defined in IEEE STD 1474.1, Communications-Based Train Control (CBTC), Performance and Functional Requirements. As a minimum this shall include:

a. The methodology of maintaining safe train stopping
b. The effects of minimum operating equipment that a train is permitted to operate in ATO
c. The effects of subsequent equipment failures and ATP failures
d. The parameters used in the calculation of the ATP design, including:
    i. Overspeed tolerances
    ii. Rollback tolerances

iii. Minimum assured braking rates

iv. Reaction times.

11.1.3 Unauthorized Motion Prevention

The ATP subsystem shall ensure that irrevocable emergency brakes are applied to a train if there is unexpected, or unauthorized, train movement when the train is supposed to be in a stopped condition, or when the train moves in a direction other than the commanded direction of travel (rollback). Reset and restart shall be possible both remotely by the Central Control Operator and manually by transit personnel on board the train.

The permitted rollback distance shall be determined by the Contractor and stated at design review.

11.1.4 Overspeed Protection

The ATP system shall provide a safety-critical overspeed-protection function to preclude a train's speed from exceeding the speed limit determined by the Contractor in any part of the System.

The permitted overspeed tolerance shall be determined by the Contractor and stated in the Safe Train Separation Methodology document as described in Section 11.1.2.

In Recovery Manual Mode (RMM) with ATP, the ATP subsystem shall ensure that the train does not reach speeds above maximum permitted manual speed. The Contractor shall specify the maximum permitted manual mode speed and include this information at design review and in the SOFRP. In RMM (without ATP), safety is assured procedurally under supervision of the CCO.

11.1.5 Parted Train Protection

The ATP subsystem shall ensure that if a train is parted, all vehicles of the train shall immediately and irrevocably apply their emergency brakes. The ATP subsystem shall ensure that all parts of the train are protected.

11.1.6 Signal Transmission and Detection

Commands transmitted to the train from the wayside shall be protected from external interference due to factors such as power transients, radio interference, cross talk or oxidized contacts. In particular, such interference shall not cause unsafe train operation.

All signals that involve the ATP subsystem shall be continuous or of such a repetitive nature that interruption of any such signal shall, after a time delay sufficient to allow for minor gaps in detection circuits or transmission, and equipment operating time, initiate braking, unless otherwise specified herein.

If the movement authority signal is lost, the train or vehicle shall be commanded to brake to a stop. If the movement authority signal is subsequently restored, and all other safety criteria are satisfied for the train to proceed, the train shall continue at the commanded speed.

11.1.7 Unscheduled Door Opening Protection

The ATP subsystem shall ensure that no automatic mode failure shall result in the unlocking or opening of a vehicle door.

If any vehicle door or emergency exit unlocks or opens while a train is in motion, an alarm shall be sent to the Central Control Operator and the train shall be automatically routed to the next available downstream station, regardless of its current destination, and held with all doors open until released by Central Control Operator command. If the train comes to a stop before reaching the next station, it shall not re-commence motion unless released by an on-board reset.

11.1.8 Door Alignment Interlocks

The ATP subsystem shall ensure that automatic opening of train and platform doors shall occur only if all of the conditions listed below are satisfied and the ATP subsystem verified:

a) The train speed is zero.

b) The train is properly aligned with the station platform, and

c) The brakes have been properly applied and power has been removed from the propulsion motors.

Automatic train door opening under any other conditions shall not be possible pursuant to the safety principles described in Section 0.

Train-station misalignment or failure of doors to open shall initiate the actions required in Sections 11.2.1 and 11.2.2.

11.1.9 Departure Interlocks

The ATP subsystem shall ensure that a train stopped in a station shall not be allowed to move unless all train and platform doors are properly closed and locked and the train brakes have been commanded released. Should confirmation of the release of the brakes not be received within a specified time, dependent on the Contractor’s brake design, the train shall be commanded to stop, either normally or with the Emergency Brakes. Independent of which method is used to stop the train, the Emergency Brakes shall be commanded applied when the train comes to a stop, and the reset of these shall only be possible by an on-board reset.

11.1.10 Platform Door Interface

The ATP subsystem shall also control the Platform Doors. This control shall be performed through a Platform Door Controller (PDC) or equivalent. The ATP subsystem shall control the vehicle doors on a per “side” basis for normal operation, and on an individual basis for recycle operations. The platform doors shall be similarly controlled on a “platform” basis and individually.

The ATP subsystem shall supply the following commands to the PDC (as a minimum); Enable (Vital) and Open (non-Vital). The removal of the open command will be interpreted by the PDC as a Close command. These signals shall be interlocked with the same commands on the vehicle.

The ATP subsystem shall receive the following status from the PDC: Closed and Locked Status (CLS) (Vital) and Door Closed Status (DCS) (non-Vital), depending on the exact interface utilized. The purpose of the CLS is to indicate to the Vehicle Door Controller whether a recycle shall be initiated. Similarly, to the above interface, the PDC shall convey which door is affected. The Vital CLS would be used to determine if it is safe to depart the station.

An independent Locked Out (LO) status shall also be supplied, to indicate when a door has been locked out or is otherwise inoperative.

It is envisaged that the ATP subsystem Vital platform door status lines will be provided on a per platform zone basis, while the ATP subsystem non-Vital platform door status lines will be provided on a per platform door basis. The actual configuration will be subject to Client's review and will be dependent on the Contractor's actual system(s) employed.

11.1.11 Platform Door / Station Arrival and Departure Interlocks

The ATP subsystem shall monitor the status of the Platform Doors, as well as other inputs necessary to determine proper alignment at the station.

If an invalid or unexpected platform door status is received, the ATP subsystem shall ensure that the station area is closed to trains and any movement in or into the upstream area is disallowed. In the case where there is a train occupying the station area when the Platform Door status is lost, the ATP subsystem shall close the station area to trains, so that both adjacent areas have No Motion allowed. The ATP subsystem shall ensure that the station area remains closed, following a normal train dwell, until the Platform Door status is registered as correct and a request is received to open the area. The Central Control Operator shall be able to request the block be opened, after status is restored.

If a train is occupying part of the affected area when the station area is closed, it shall be caused to emergency brake (EB). In this case resumption of automatic operation (for a train that has EB'd) shall require a remote reset of the Emergency Brakes at Central Control, after the area has been re-opened.

11.1.12 Reverse Operation Interlocks

Reverse running shall be possible on all of the automatic territory of the System. Except for reversing at stations and Contractor pre-defined automatic reversal points for ATO-governed failure management operations, all other train reversing commands shall be initiated by the Central Control Operator.

11.1.13 Route Interlocking

Sufficient guideway shall be reserved for a train such that train movements through any portion of the guideway, including switches or other points, shall physically not interfere with any other train on any other portion of the guideway.

Before a train is authorized to proceed through a section of track, including a switch, the ATC shall:

a) Ensure that no other train is within the effective area.

b) Ensure that no other train approaching the area has been authorized to enter the effective area.

c) Ensure that the travel through the area will not result in a conflict with another train routing, and

d) Ensure all of the criteria specified in Section 11.1.19 are satisfied.

A capability for the remote-control movement of switches from the Central Control Facility shall be provided.

11.1.14 Service Brake Failure Protection

In the event that train service brakes fail, the train emergency brakes shall be applied in a manner consistent with the safety principles required in Section 0. Brake reset shall be by remote command from Central Control or locally on board the train.

11.1.15 Speed Measurement

Fail-safe principles shall be employed in the ATP subsystem for measuring train speed.

11.1.16 End of Track Protection

In automatic operation, near the ends of guideways, the overspeed protection function, as specified in Section 11.1.4, shall ensure that under the worst case conditions the train shall not overshoot the stopping point and strike the buffer.

11.1.17 Facility Door Detection and Response

Requirements for facility door detection and response are discussed in Section 18.2.10.

11.1.18 Obstructed Motion Detection

Obstructed motion shall be detected, and the train shall be safely stopped, and the condition shall be annunciated in the Central Control Facility. Manual and remote brake reset shall be provided.

11.1.19 Switch Interlocking, Safe Switch Mechanisms and Safe Switch Principles

11.1.19.1 Basic Switching Principles

In addition to the requirements specified in Section 11.1.13, powered actuated switching mechanisms shall comply with the following:

- When the switch is set in a position corresponding to the commanded position
- The power shall be removed from the mechanism
- Mechanical lock(s) shall be engaged to prevent switch motion
- A train shall not be permitted to proceed through or closer than a safe distance from a switch unless the ATC system continuously verifies that the switch is:
- Locked
- In the correct position for the current train routing
- "Continuous" shall include monitoring of a repetitive nature that accomplishes the same function
- If switch verification as defined above is not received, the ATP subsystem shall ensure that approaching trains stop before reaching the switch
- If switch verification is lost while a train is in the switch zone, or has been permitted to proceed through a switch by the ATC system, the ATP subsystem shall emergency brake that train immediately
- Brake reset shall be locally on board the vehicle
- Loss of electrical power to a switch shall not cause any change of switch status and the mechanical lock shall remain in position

- Switch verification and its use, and all other actions of the ATC system relating to the safe operation of switches, shall satisfy the interlocking requirements of Section 11.1.19.2. All elements of the switch control system shall be in accordance with the safety principles of Section 0.

11.1.19.2 Safe Switching Mechanisms

All switching mechanisms shall provide continuous, positive guidance (steering) to trains as they are traversed.

Switches that operate during any of the System's operating modes or during the transition between two operating modes shall be automatic and subject to the ATP requirements of this section. Power-actuated switch mechanisms shall be operated by electric, hydraulic, or pneumatic actuators.

All switching mechanisms shall meet the following requirements:

- Alignment Detection: A means shall be provided to detect that the main element(s) of the movable portion of the switch is at either end of the physical displacement it undergoes during actuation
- Actuator Power Removal: A means shall be provided for removing power from the switch actuator
- Mechanical Locking: A means shall be provided to mechanically lock the position of those switching elements which directly interact with the train and guideway to cause the switching of the train and which move to change the state of the switch from tangent to turnout. This means of locking shall keep the switch safely locked under the force of a moving train in the switch and the force, in either direction, of the actuator. Power shall be removed from the mechanical lock after its actuation is completed
- Locking Detection: A means shall be provided to detect that the switch mechanical lock is in the locked position; the position of the lock shall be sensed directly from the lock itself.
- Position Detection: A means shall be provided to detect that each switch point, on any switch whose accurate positioning is essential to safe initiation of the switching interaction between train and guideway and which moves to change the state of the switch, is positioned with sufficient accuracy to ensure safe travel through the switch.

11.1.19.3 Manual Switch Operation

All switches shall allow local manual operation by one person without normal switch activation power. Manual actuation equipment shall be secured and locked to avoid unauthorized use.

The status of the switch shall be indicated to the operator of a manually controlled vehicle approaching the switch. A power disconnect device shall be provided to enable maintenance personnel to disconnect power to the switch and avoid switch actuation.

11.1.19.4 Switching Safety

Both power- and manually actuated switches shall be interconnected with the ATP subsystem to assure safe operation of trains through the switches. The ATP subsystem shall prevent a train from entering a switch that is unsafe and shall not command a switch to an unsafe condition once a train is committed to traverse it.

Control circuits shall be arranged so that a switch cannot be signaled for a route until each portion of the switch is indicated to be in the proper position through circuit controllers, such as position detectors, powered actuation detectors and locking detectors operated directly by the switch and/or by the locking mechanism (that is, the switch is aligned-and-locked).

Whether the switch is activated automatically or manually, when conditions at the switch are not safe for the movement of train, the control signals normally transmitted to approaching trains shall ensure that any such train in automatic operation shall stop a safe distance from the switch.

Whenever a train is in the protected zone associated with a switch, or a series of switches, route locking shall prevent the movement of any of the switches in the protected zone and shall prevent any conflicting train movements from occurring.

The ATP subsystem shall prevent the automatic or manual unlocking of a switch after a train has been committed to traversing it until the train has cleared the switch. Protection against inadvertent release of locking due to momentary loss of power or vehicle detection shall be provided.

The above-described principles of approach locking, route locking and detector locking shall apply for all types of switching.

11.1.20 Interior Vehicle Door Emergency Release Inhibit

The ATP subsystem shall provide a Vital interior emergency release inhibit signal for each side of the train to indicate safe side evacuation to a platform or walkway. Please see Section 9.10.2.10.

11.2 Automatic Train Operation (ATO)

The ATO subsystem shall include the equipment necessary to perform the following functions automatically and within the constraints of the ATP subsystem:

a) Execute train stops, dwell times, and departures.

b) Control operation of train doors.

c) Operate trains at ATS and CCO assigned speeds, within the limits imposed by the ATP subsystem, and

d) Regulate train acceleration and jerk within specified passenger comfort limits.

11.2.1 Stops, Dwells and Departures

The ATO subsystem shall control train speed and deceleration rates to stop trains within the specified tolerances. The ATO system shall control train braking and propulsion commands to provide a smooth stop, avoiding jerk as the vehicle comes to rest. Parking brakes shall apply when zero speed is detected.

An automatic jog forward feature shall be implemented in the Contractor’s design to allow recovery from an initially missed station stop position. Such maneuvers shall be limited to a maximum of one attempt. Trains that do not stop (after jog attempt, if so designed) within the correct station/train alignment tolerances shall automatically proceed to the next scheduled station. An alarm shall alert the Central Control Operator to this condition.

After the station dwell has expired, the ATO shall automatically command the train doors to close. Once it is confirmed that all doors are closed and locked, the ATO shall command the train to depart the station.

The ATO system shall have default Station Dwell Times defined for each individual station platform, which shall be used for all unscheduled train operations. The Central Control Operator shall have the capability to adjust these dwell times on an individual station platform basis.

The Contractor shall determine and document the stopping tolerances and accuracy of its design.

11.2.2 Door Operation

If for any reason any door fails to open or close as commanded, automatic corrective action shall be undertaken. The Central Control Operator shall be apprised of the situation by the ATC system. As a minimum, the ATC shall report that not all doors are open or closed. The Central Control Operator shall be able to attempt to open or close the door(s) remotely, hold the train for local manual intervention by O&M personnel, or, in the case of one or more doors failing to open, dispatch the train to the next station.

Train doors shall be automatically controlled except when a train is in Recovery Manual Mode, when the train operator shall control the operation of all train doors.

If during the closing cycle, an obstruction is encountered on either the platform or vehicle doors, that door and its associated partner shall be recycled in accordance with Section 9.10.2.

11.2.3 Train Movement Control

The ATO system shall, in combination with the propulsion and braking control circuits of the vehicle, control the vehicle movement and speed to:

- prevent rollback when starting at any position on the guideway
- Meet the acceleration and jerk limit requirements of Section 9.6.3
- Stay within the speed limits imposed by the ATP subsystem
- Avoid overspeed conditions
- Avoid unnecessary transitions in tractive effort
- Provide the smoothest practical ride for passengers.

11.2.4 Loss of Propulsion Power

If propulsion power is interrupted, a train may coast under ATO control and within the ATP constraints. Should the train reach zero speed, brakes shall be applied, and the train shall remain stationary until traction power is restored.

11.2.5 Other Operating Configurations

When initiated by the Central Control Operator, the operation of the System in the other operating configurations (than line haul) such as shuttle or skip stop shall be accomplished automatically through the ATS subsystem. The recommended routes and station stops for these other configurations shall be predetermined and included in the ATS subsystem for Central Control Operator selection. Station Dwell Times shall be controlled by the ATS subsystem. The dwell time at each station shall be individually adjustable by the Central Control Operator.

11.3 Automatic Train Supervision (ATS)

The ATS subsystem shall orchestrate, monitor, and display most of the train operations of the System and will be the most significant interface between the Central Control Operators and the ATC system.

The ATS subsystem shall:

a. Display System status and present target headway
b. Provide a suite of Central Control Operator commands and functionality to permit efficient supervision and management of System operation
c. Display and record all train movements, System performance and status data.

11.3.1 Safety Constraints on ATS

The ATS subsystem shall be designed such that no action or lack of action by the Central Control Operator, either purposefully or inadvertently, or any malfunction of the ATS equipment, can subvert or compromise the ATP subsystem functions and thereby cause an unsafe condition. Thus, the ATP subsystems shall take precedence over the ATS subsystem. Should the ATS subsystem become inoperative, the System shall be able to continue to operate in the automatic mode under the ATO subsystem and protected by the ATP subsystem.

11.3.2 Performance Monitoring

System performance information at Central Control shall be provided on the displays required by the subsequent sections. These displays shall be readily expandable to accommodate the expansion of the System contemplated in Section 3.6.

The design, layout, displays, information displayed, controls, and human interfaces of the Central Control Room shall be developed by the Contractor based on human factors analysis.

11.3.2.1 System Schematic Display

The System schematic display shall provide visual representation of the real-time operating conditions throughout the System. The display shall adhere to ergonomic principles and shall:

- Show details of the operating System
- Show the automated portion of the OMSF
- Show approximately scaled graphic representations of the guideway, stations, switches, OMSF, and other relevant physical features
- Incorporate sufficient information to permit the Central Control Operators to manage the System efficiently, such as track occupancy, train parking, and storage locations.

For each train in the automatic portion of the System, show:

- The location and identification
- The direction of travel
- The number of vehicles/trains
- The region of guideway reserved.

For each switch in the automatic portion of the System, show:

- The direction a train would follow through it
- If it is moving or stopped and locked
- If it is reserved by a train
- If it is reserved by a Central Control Operator
- If it has any faults.

For each station platform in the System, show:

- The active or inactive status
- The intrusion detection system status.

11.3.3 Service Operation

The prime function of the ATS subsystem is to provide the facilities to enable the System to supply a desired carrying capacity while taking into consideration the normal passenger-induced delays. To achieve this, the ATS subsystem shall operate the System in accordance with a predefined configuration. These may include line haul, skip stop, start-up, shutdown and failure management configurations. The number of trains operating, and the configuration in which they are operating, will vary throughout the day to efficiently tailor the System capacity supply to the demand, or to vary the Service Interval as desired.

11.3.3.1 Operating Configuration Development

The Contractor shall define all the routes that are supported by the ATS, as well as the combinations of these routes that can be used to determine the operating configuration. For the purposes of this contract, the Contractor shall predefine the operating line assignments that are necessary to execute the normal scheduled service and the failure management service identified in the SPFMA (system performance failure management analysis).

11.3.3.2 Schedule Operation

The ATS subsystem shall enable the operating personnel to select and implement routes according to the operating mode.

For each regulated train, the ATS subsystem shall indicate a train's performance in relation to the train's headway by selection of the appropriate pull-down menu.

11.3.3.3 Automatic Train Regulation

The ATS subsystem shall provide Automatic Train Regulation (ATR). It shall not be necessary for Central Control personnel to intervene in the operation of the railway to achieve regular train service under normal circumstances with the normal perturbations anticipated.

The ATR facility shall be designed to:

- Avoid train bunching by equalizing intervals between trains
- Provide service operation at the target headway.

The ATR facility shall:

- Calculate a Service Interval variance for each scheduled train at each scheduled platform by subtracting the target headway from the measured headway

- Attempt to correct Service Interval variances to zero by adjusting station dwells. The amount of correction shall be within the minimum and maximum dwells that have been defined for a particular platform.

The ATR features shall operate without human intervention but may be overridden by the Central Control Operator.

11.3.4 Central Control Operator Facilities

The Central Control Room operating personnel shall be provided with facilities and capabilities, provided by the ATS and SCADA systems to enable safe and efficient operation of the System.

All equipment, computer hardware and software, peripheral equipment, data storage equipment, other devices, and associated efforts necessary to provide the functions and capabilities described in this section shall be furnished by the Contractor. The Contractor's design of the Central Control Operator functions and facilities shall be subject to review by the Client as part of the ATC Design Review.

The facilities supplied shall include the following:

a) Train Identification: Train/Vehicle identification numbers shown at the Central Control Facility, used by the Central Control Operators for input to the ATS subsystem, and used by the ATC system, shall be similar to the numbers/markings on the vehicles/trains.

b) Train Dispatching: The Central Control Operator shall be able to alter System service at any time by selecting and implementing changes to the existing operation. The CCO shall be able to dispatch each train individually, or all trains globally, onto a route.

c) Train Routing: It shall be possible to route trains to any point in the System. Train routings shall be accomplished by selecting a train and a destination on the ATS subsystem System Schematic Display.

d) Termination of Service: The CCO shall be able to terminate System service at any time.

e) Operating Configuration Selection: The Central Control Operator shall be able to assign each train individually, or all trains globally, to any of the available operating configurations. This shall include selecting the trains, route, stations, and dwells for that mode-specific operating configuration. It is permissible to require independent actions to perform these selections.

f) Printing: The CCO shall have the capability to print all ATC system reports, logs, alarm histories, user lists, etc. by selecting a print option when viewing each. “Print Screen” is not adequate for this requirement. The Contractor shall supply the printer and all associated equipment.

g) Door Actions: The CCO shall be able to control the following door actions at stations, including overriding automatic door operations, subject to the conditions of Section 11.1.8 for the entire train:

    - Open and close
    - Hold open.

h) Modify Train Operations: The CCO shall be able to issue the following commands which modify normal train operations:

    - Reset brakes (e.g. after an EB) on any train

- Dispatch one or more trains from a station and/or a specified location on the guideway to a station and/or specified location on the guideway; for each train, each station, and all locations on the guideway
- Safely stop an individual train, or all trains, anywhere in the System
- Once stopped, a train may be re-directed by the CCO
- Modify train speeds on a train
- Train-Hold Functions: The ATS system shall be capable of allowing the CCO to select two types of train hold:

1. A station may be designated as STATION HOLD, whereby a train that is already stopped at the station or every train that stops at the station shall be dispatched by the CCO in order to continue in scheduled operation. The System Schematic Display (SSD) shall indicate which stations have this feature active.
2. Implement a SYSTEM HOLD, whereby every train in the System is held at its present platform if it is currently dwelling or proceeds to the next scheduled station and dwells indefinitely. The CCO shall be able to dispatch all trains into service by revoking the SYSTEM HOLD. The SSD shall indicate that this feature is active.

i) Remove Train from Service: The CCO shall be able to direct a train to proceed out-of-service to any storage area in the System. The train shall continue its route until the out-of-service platform is reached, at which location it shall hold with its doors open.

j) Failure Mode: The CCO shall be able to convert the System from its normal operating configuration to a lesser operating configuration for failure management purposes.

k) Modify System Dwell: The CCO shall be able to vary the dwell time for each station independently. The range of dwell times and adjustment increments shall be in accordance with values agreed to at the Design Review.

l) Platform Close: The CCO shall be able to command any platform to be designated as closed. This shall cause all trains to proceed through the station without stopping.

m) Close Station: The CCO shall be able to close a section of track, effectively blocking that segment to the traffic.

n) Brake All Trains: The CCO shall be able to brake all trains on the guideway by activation of a single-action button or switch. One button shall be located at each of the CCO work positions. A deliberate and positive action shall be required to release the button to eliminate the emergency brake condition.

o) Alarm, Fault, or Change of State Message Display Processing: The CCO shall be able to receive, acknowledge, store, and recall alarm message displays and acknowledge accompanying audible alarms from all ATC, power, and communications subsystems. This may be achieved through the use of different screens for the different subsystems. This requirement may be satisfied through the ATS subsystem and/or through the SCADA system (see Section 13).

p) Automated Storage Facility Operation: The CCO shall be able to control the movements of vehicles and trains in the automated storage facility.

11.3.5 Alarms and Malfunction Reporting

The ATS subsystem and / or the SCADA system shall provide status information to the CCO to support System monitoring and failure diagnostics. Prioritization of the ATS /SCADA alarms shall be based on potential safety implications, unplanned service stoppages, and general failure detection. The ATS and / or SCADA subsystems shall annunciate all alarms by both incident message and by audible alarm. All alarm messages shall indicate specific location and type of fault being annunciated. All alarm messages shall be indexed, and time stamped. Acknowledgement of an alarm by the CCO shall cause the audible alarm to cease, but the malfunction indication shall persist until the malfunction is cleared.

Alarms shall be categorized into those requiring:

- Immediate removal of train from service
- Removal from service during next round trip
- Removal from service during next scheduled service reduction.

ATS and SCADA alarms shall include but not limited to:

- Train EB
- Brake failure
- Unplanned door opening or unlocking
- Unplanned switch movement
- Parted train
- Unauthorized train motion
- Loss of ATC signaling
- Loss of ATP
- Loss of any ATP controlled condition
- Any failure resulting in emergency brake application
- Loss of presence detection
- Vehicle smoke or fire alarm
- Vehicle suspension failure, including deflated airbags and flat tires
- Loss of traction or station power (SCADA)
- Propulsion faults on a vehicle
- Motion obstructed
- Doors fail to open after being commanded
- Doors fail to close and lock after being commanded
- Train-station alignment tolerance exceeded
- Other power distribution overload or fault
- Vehicle batteries low or battery charger fault
- Loss of public address in trains or stations
- UPS malfunction
- Removal of a vehicle or station fire extinguisher
- Low vehicle tire or air bag pressure
- Vehicle HVAC failure
- One or more critical lights out
- Loss of CCTV in a station

- Failure of vehicle emergency door/exit mechanism.

The Contractor shall develop a list of major and minor alarms and determine all actions to such alarms, including those in the Central Operations Manual. The list shall reflect both the unique characteristics of the Contractor's equipment and the proposed operational and response procedures.

11.3.6 Data Recording and Reporting

11.3.6.1 Data Recording

The ATS subsystem shall keep a record of the identification numbers of the trains and the vehicles operating in each train. The ATS shall display the operating configuration in which the System is functioning and the route to which each train is assigned. It shall also record data which can be utilized to determine System Service Availability performance, and any unscheduled stoppage or delay including time of occurrence and time of resumption of operation, with the identification number(s) of any train(s) affected.

The ATS subsystem shall include the recording on suitable digital media of all data transactions between Central Control and other portions of the System. These transactions shall include all vehicle/train reports with vehicle/train identification numbers, location, status, and malfunctions, alarms, and acknowledgments, CCO console commands, times of train insertion and removal, changes in the operating mode, and other ATS-initiated activities and pertinent data. All such data shall be recorded in a format that includes the date and exact time of each data transmission. Data shall be recorded in a format suitable for both a permanent file and random-access retrieval for use with the management information system data processing software that shall be provided by the Contractor.

The Contractor shall provide appropriate procedures, hardware, and software to store, retrieve, and analyze these data.

11.3.6.2 System Availability and Operations Reports

System Availability and Operations reports facilitated through the ATS subsystem and/or other System resources such as the SCADA subsystem. The data recording and reporting function shall include tools to permit the analysis of accumulated data and the preparation of System operations reports. These Systems operations reports shall be prepared daily, weekly, monthly, and annually using data automatically accumulated from the data records described above. The System operations reports for each period shall include at least:

- Fleet Availability
- System Service Availability
- Downtime events.

The Contractor shall develop a list of data storage, analysis, and reporting capabilities.

In addition to the computer -generated reports, the Contractor shall develop procedures and formats to report on other aspects of daily, weekly, monthly, and annual operations activities. Such reports shall include as a minimum any incidents, accidents, and other unusual events or problems.

11.4 ATC System Reliability

11.4.1 Redundancy

To assure safety, all ATC computers/processors, essential peripherals, and wayside transmission equipment, which pertain to safety or provide safety information shall contain checked-redundant or equivalent elements to provide automatic on-line and frequent self-checking diagnostic features to detect failure or loss of any function. Upon detection of such failure or loss of function, the diagnostic feature shall notify the CCO by audible alarm and displayed message identifying the failure. The interpretation of these signals may be made in a safe manner by utilizing a combination of persistency (two or more identical transmissions), Cyclic Redundancy Checks (CRCs), and consistency (i.e., the information contained in the transmission is as expected, according to the database).

To assure reliability, the design and operation of the ATS system elements shall be such that normal train operations with Central Control Room display and command capabilities are not disrupted for a period exceeding one minute. This design feature may be accomplished by automatic switchover to hot standby equipment or by manual switchover to standby redundant equipment by a CCO, provided the one-minute disruption criterion is satisfied. Failure of non-redundant equipment such as station equipment shall be clearly indicated to the CCO so that appropriate actions may be taken.

The train shall be equipped with two On-Board Control Units (OBCUs) with an automatic failover feature.

11.4.2 Software Requirements

Existing, proven software shall be used to the maximum extent possible. Any computer software used in the ATC system shall be structured in a functional hierarchical system. In this top-down approach to software design, successive levels within the hierarchy shall be obtained by desegregating and partitioning the software into blocks with progressively greater functional detail. Software design and documentation shall conform to current established engineering standards of the ISO 9000 series.

11.5 ATC Functionality Testing

Trains inserted into revenue service shall be tested for proper ATC functionality prior to entering service. This shall apply to trains stored in the OMSF, or at end station platforms or other storage location. The final list of items to be checked and the detailed functionality test will be determined and shall be reviewed during the design review process.

12 Communications Subsystems

The Communications subsystems shall consist of:

- Communications Transmission Subsystem (CTS)
- Radio Communications
- Video Surveillance
- Telephone Communications
- Public Address (PA)
- Passenger Audio Communications
- Passenger Information Displays (PIDs)
- Video and Voice Recording Subsystems.

12.1 Communications Transmission Subsystem (CTS)

The CTS shall distribute audio, video and data communications between passenger stations, substations, the OMSF and CCF and other locations along the guideway as required.

The CTS shall be using fibre-optic technology and its design shall be sufficiently redundant and reliable to meet System dependability requirements 24 hours a day, 7 days a week. It will provide an aggregate channel carrying multiplexed signals including those to and from:

- Communications equipment (in this Section12)
- SCADA equipment (in Section 13)
- AFC equipment (in Section 15)
- ATC equipment (in Section 11)
- Station equipment (in Section 18)
- Power Supply and Distribution equipment (in Section 10)
- Guideway-mounted equipment (in Section 17)
- Vehicle-borne equipment via Wifi Access Points along the guideway.

The design of the CTS shall:

- Be based on a modular architecture
- Facilitate the System expandability contemplated in Section 3.6
- Provide protection against the failure of any single fibre-optic cable or fibre
- Provide a graphic user interface to centrally manage and control the CTS
- Indicate status alarms, link performance data, configuration information
- Have the capability to diagnose major faults from the CCF and remotely.

12.2 Radio Communications

Radio transmission shall provide the primary communication method where it is impractical to provide hardline communications. The Contractor shall supply a radio system that provides two-way radio communication over four (4) channels subject to the availability and licensing restrictions in the area of the System. The Contractor shall provide all necessary radio communications hardware, including at the CCF, base stations (at stations and the OMSF), portable equipment (on trains) and mobile equipment (for O&M personnel in the field), antennas, antenna towers, and related equipment. All equipment shall conform to local requirements. The Contractor shall assist the Client in finding, obtaining and licensing all radio frequencies to be used on the System.

The Contractor shall provide the appropriate quantity of radios and associated equipment to provide adequate radio coverage for the Operation and Maintenance of the System. Two radio channels shall be allocated to this function.

One radio channel shall be used to provide PA announcements to passengers on trains and for passenger audio communications. One channel shall be provided for data communications between trains and the CCF.

The radio system shall provide a signal quality as per applicable standard. Required locations include at-grade and aerial portions of the Right-of-Way. The intelligibility of radio communications shall meet the requirements of the applicable standard.

Requirements for Voice Recording can be found in Section 12.8.

12.3 Video Surveillance

The Contractor shall provide a color Closed Circuit Television (CCTV) system, including cameras, transmission system and monitoring stations. The CCTV system shall provide clear coverage of embarking and disembarking areas of all station platforms as required for operational purposes. CCTV monitors shall be provided in the CCF control room and the OMSF. CCTV displays shall be discernible under normal operating conditions. Cameras shall be the low-light charge coupled device (CCD) type and be a combination of fixed and pan-tilt-zoom models. Cameras shall have a "usable picture" with scene illumination from 0.3 Lux up to bright sunlight, using automatic light compensation. Station cameras shall be provided with “auto iris” feature.

The video surveillance system shall utilize the CTS to transmit information from cameras to monitors.

12.3.1 Passenger Station Equipment

The CCTV cameras shall be vandal resistant. Installations shall be suitable for the environment. The cameras shall automatically adjust to the ambient light conditions of each station throughout the operating day and night.

Each station shall be equipped with a suitable number of CCTV cameras, viewing loading / unloading area near the platform screen doors other public areas, including fare gates, ticket vending area, station attendant’s booth, escalators and grade-level entrance to elevators.

12.3.2 Central Control Equipment

At the CCF, two monitors shall be provided for each passenger station. A master monitor shall also be provided at each CCO position. CCF personnel shall have the ability to display, on the master monitor the video signal from any station platform. Location identification, in alphanumeric format, of each camera shall be clearly superimposed upon the video display image at all times. Regardless of the final quantity and configuration of cameras and monitors, the CCTV system shall provide the following functions:

a) The CCTV operator shall have the ability to select any video signal from any station, to be displayed on a master monitor.

b) The CCTV system shall be capable of automatically switching the video signal displayed on any master monitor, either sequentially, or selectively.

Requirements for Video Recording can be found in Section 12.8.

12.4 Telephone Communications

The telephone communications subsystem shall serve both passengers and O&M personnel.

A PABX located at the CCF / OMSF shall provide necessary switching for telephones distributed within the System. The following is a list of facilities and functionality that shall be provided:

- CCF / OMSF PABX
- Office telephones
- Operational telephones in stations, sub-stations and Blue Light stations, etc.
- Passenger assistance telephones in stations
- Voicemail for CCF / OMSF telephones
- Automated attendant
- Network Management Subsystem (NMS).

The CTS shall provide the transmission medium for telephone circuits interconnecting telephones at each station with the PABX.

The PABX shall be controlled by a redundant controller. Peripheral shelves shall provide sufficient number of trunks for public switched telephone network (PSTN) and line inputs to exceed the initial needs with 30 % spare capacity and shall support 100 % expansion by adding additional cabinets.

A Network Management Subsystem (NMS) shall be provided with the PABX at the CCF / OMSF. The NMS shall log and report alarms and provide call detail recording.

The intelligibility of telephone communications shall meet the requirements of the applicable standard.

Requirements for Voice Recording can be found in Section 12.8.

12.4.1 Telephones

The administrative telephones in passenger stations and substations shall be conventional type analogue telephone sets suitable for desk and wall mounting. Administrative telephones supplied for OMSF offices shall be digital sets.

A Blue Light Telephone handset shall be provided for each blue light station. The handset cord shall be of an armoured type. Removing the handset from the cradle shall place a call to the CCF.

Passenger assistance telephones shall be located in each passenger station to allow passengers to communicate with the CCO. The units shall be hands-free, pushbutton activated intercom units. Pressing the button shall automatically place a call to the CCO. Two passenger assistance telephones shall be provided on each platform and two in each station concourse. Another shall be installed in each station elevator.

Each CCO position shall have an attendant type, common console telephone set. One button access for emergency services direct line telephones and other key telephone locations shall be provided.

The CCOs shall have access to PABX features via the attendant console. The console alphanumeric display shall show source and destination calls. The incoming calls shall be queued chronically and answered in order. Telephone identification shall be provided. Identification shall include the extension number and a descriptive name. This feature shall be used to identify the location from which an emergency call originates.

12.4.2 PABX Extension Line Locations

Within passenger stations, substations and the OMSF, extension lines shall be provided as follows:

- In each equipment and plant room
- In each operational and control room
- In each office and staff common room.

Telephones in equipment rooms shall be installed in party lines, as they will receive limited use.

12.5 Public Address (PA)

The Contractor shall provide a Public Address (PA) subsystem servicing all vehicles, each passenger station, and the OMSF. The PA subsystem shall be used to provide audible routine and emergency announcements for passengers and O&M personnel.

The PA subsystem shall be comprised of a Central Control Station at the CCF / OMSF, PA amplifiers and controllers in each passenger station, and at the OMSF, and announcement panels at each passenger station.

Station announcement panels shall allow local live announcements over the local PA subsystem. Messaging initiated on an announcement panel shall take priority over any other PA source, except from the fire panel. The status of passenger station announcement panels shall be provided to the Central Control Station.

The PA subsystem shall be supervised, with anomalies being reported at the CCF.

The Central Control Station shall be capable of broadcasting live messages to any individual passenger station, or the OMSF, or simultaneously to all stations.

The PA system shall automatically broadcast pre-recorded audio messages to passenger stations based on input from the Automatic Train Control System.

Automatic station PA announcements shall include:

- Train Service Interval
- Destination of arriving train

- Train out of service.

Manually initiated PA messages initiated from the CCF shall include:

- Evacuation message
- Station closing message
- Service delay message.

The PA system on-board each train shall interface with the on-board train control system to receive message triggers. Automatic on-board train announcements shall include:

- Name of next station stop
- Door close warning
- Train going out of service.

The PA system design documents shall define all recorded announcements to be provided.

The intelligibility of the PA system shall meet the requirements of the applicable standard.

12.6 Passenger Audio Communications

A duplex communications system shall be provided to permit two-way voice communications between CCOs and passengers or O&M personnel within each passenger compartment of each train. Activation of two-way voice communications between the CCO and the train(s) shall be possible only from the CCF. Passenger-initiated communications requests from a train, including the passenger compartment identification number, shall automatically be displayed on the CCC for the CCO to activate the communications link. The display shall also show any queue of such communication requests. The CCO shall be able to activate this link upon receiving an indication of the passenger-initiated communication request or at any time the CCO deems it necessary to receive communications from a car (eavesdropping feature). A passenger-initiated communications request shall include an audio and visual on-board indication that the call has been requested. No indication shall be provided if the CCO initiates an unrequested communications link.

Passenger audio communications between the trains and the CCF shall be carried by the radio communications subsystem.

The intelligibility of passenger audio communication shall meet the requirements of the applicable standard.

12.7 Passenger Information Displays (PIDs)

One, double sided passenger information display (PID) using suitable technology shall be provided for each platform side. Additional displays might be required on the platform as defined by client. The message content on each display shall provide passengers with information on the destination and timing of each arriving train and shall provide special messages to indicate out of service trains, System closure or failure. Normally, message content shall be triggered by the train control system. The CCO shall be able to override the automatic messaging at any station and select from a list of pre-configured messages.

12.8 Video and Voice Recording Subsystems

The Contractor shall provide audio and video recording equipment as described below. The Contractor shall provide a secure, controlled access area for the storage of recorded information. Sufficient audio recording medium shall be provided such that recordings can be retained for a period no less than thirty (30) days. The Contractor shall establish policies and procedures for the access, storage, retrieval, release and destruction of recordings. Policies and procedures shall be detailed in the Operations Manual.

12.8.1 Voice Recording System

An audio recording device shall be provided to record CCF incoming and outgoing audio communications for up to 24 consecutive hours in a single recording. The recording device shall be multi-channel, with the capability to record all CCF communications traffic, and shall include one channel indicating date and time. The recording device shall be rated for continuous operation. Recording of telephone and radio conversations shall conform to all applicable national and local laws. A method for playback and listening to any selected track of the recordings shall be provided. Playback shall not interrupt recording. A “hot” standby, or redundant, recording device shall be provided. The System shall have the capability to automatically switch to the “hot” stand-by in the event that the primary recording device fails. Manual switching capability shall also be provided. A means shall be provided to quickly replay the last 30-60 seconds of an emergency call received from a train.

12.8.2 Video Recording System

The Contractor shall supply and install video recorders at the CCF. Recorders shall be rated for continuous duty operation. Recorded video shall include the superimposed camera location identification, and the date and time of recording. Alternatively, video recorders may be distributed across the stations and networked with the CCF via the CTS.

All cameras shall be continuously recorded at 4 x Common Intermediate Format (4 CIF) resolution and at least 15 frames per second (fps) using high quality compression. Storage shall be provided for at least 5 days recording.

A separate monitor and workstation shall be provided at the CCF to allow playback and archival of recorded video.

13 Supervisory Control and Data Acquisition (SCADA)

13.1 Introduction

The Contractor shall provide an integrated hardware and software Supervisory Control and Data Acquisition (SCADA) system. The SCADA system shall complement the ATC system and the Communications system and provide all required monitoring and control functions not provided by those systems. As a minimum it will control and/or monitor the following:

- Power Supply and Distribution subsystem
- Security Intrusion Monitors
- Escalator and Elevator status
- AFC tamper alarms
- Switch Beams

- Fire alarms.

SCADA hardware shall include servers and workstations at the CCF. The system shall be interfaced to subsystem equipment at passenger stations and substations through Remote Terminal Units (RTUs). Printers shall be provided at the CCF to produce hard copies of reports generated by the SCADA system.

This SCADA hardware shall be sufficient in quantity and redundancy to meet operational and System dependability requirements.

13.2 SCADA User Interface

The SCADA system user interface shall be based on a service proven application. System Status Displays (SSD) shall have the capability of displaying at least the following:

- A representation of the track and station layout in a semi-geographical orientation
- The presence or absence of traction power in each segment of the track. This indication of power shall be shown with either a color convention normally used for electrical power, or one consistent with that of an integrated System Summary Display
- The status of circuit breakers and switches in the power supply system: closed, opened, or positioned for local control. The status indication shall include breakers operated from the control room, at the substations, or from shut-off devices in the stations or along the track
- The presence or absence of power at each primary feeder
- The presence or absence of backup power, where provided
- Summary level alarm information for all monitored systems.

13.3 Power Distribution Equipment

The SCADA system shall provide the ability to control the application and removal of power, switch power and auxiliary power separately or in combinations for the entire System consistent with the Power Supply and Distribution System (PS&D) design.

The following functions shall be provided:

- Remote trip/close control of all power circuit breakers at the at the traction power voltage level (but not for circuit breakers supplying housekeeping power for passenger stations, the guideway, or the OMSF and CCF)
- Remote open/close control of all motor-operated disconnect switches
- Monitoring of the open/closed status of all of the remotely controlled circuit breakers and disconnect switches above
- Monitoring of equipment alarms including, but not limited to, overtemperature alarms and bus-to-cubicle leakage current alarms
- Monitoring of protective trips
- Monitoring loss of control voltage and/or trip circuit voltage
- Monitoring of switchgear control voltages
- Monitoring of Uninteruptible Power Supply Units (UPS)
- Remote test and monitoring of any Automatic Assured Receptivity Units (AARUs) or wayside energy storage

- Monitoring of the total traction current load at each substation.

As an additional safety feature, a master control shall permit all power rail power to be shut off immediately with one switch or button actuation.

13.4 Security Equipment

The SCADA system shall provide the CCOs with the ability to monitor all security systems. Summary level System status and alarm status shall be available. Security system monitoring shall be coordinated with the Communications and ATC system design and shall include at least the items listed in Section 13.1.

13.5 Other Monitored Equipment

The SCADA system shall provide the CCOs with the ability to monitor and control System equipment that is not controlled by the ATC or Communication systems. Monitoring shall include status and alarm conditions for the equipment.

13.6 SCADA Alarm Management

The SCADA system shall prioritize alarms being displayed and provide an ability to easily distinguish and respond to alarms with immediate safety and security implications. Alarms shall also include audible warnings where such warnings enhance System operations. The SCADA system shall permit alteration of priorities and provide an ability to filter alarms based on location, priority, and other criteria.

Occurrence of a SCADA alarm condition that requires acknowledgement shall be shown on each base display. On the System summary display, the occurrence shall be shown graphically, and shall be shown in text format if selected by the CCO. The CCO shall be able to view each alarm or all alarms. The CCO shall be able to acknowledge one alarm, or all alarms, with a single keystroke or pointer equivalent.

13.7 System Master Clock

The Contractor shall provide a System Master Clock to indicate accurate, reliable date and time-of-day information to connected subsystems. The System Master Clock time shall be used to synchronize date and time of day information, in all CCF equipment where such information is required.

13.8 System Availability

The SCADA system shall operate 24 hours per day, seven days a week. Components that pertain to safety or provide safety information shall contain checked-redundant or equivalent elements with automatic on-line and frequent self-checking diagnostic features to detect failure or loss of any safety function. Upon detection of such failure or loss of function, the diagnostic feature shall notify the CCO by audible alarms and displayed message identifying the failure.

14 Central Control Facility and Equipment

14.1 Central Control Facility (CCF)

The Contractor shall design and construct the Central Control Facility (CCF) and shall design, supply, install, test and commission the subsystems and equipment there so that the Operation and Maintenance of the System can be properly and efficiently monitored and controlled. At the discretion of the Contractor, the CCF may be a single room or alternatively a main control room with one or more associated equipment and /or storage rooms.

The CCF shall be located at or within the OMSF.

The CCF shall be sufficiently large to house:

- A main operating console with two Central Control Operator (CCO) positions
- ATS and any other ATC equipment and displays required at the CCF
- SCADA equipment and displays required at the CCF
- Communications equipment and displays required at the CCF (including CCTV monitors)
- Position for a shift supervisor and spare seating for additional personnel
- Cabinets and / or shelves for storage of documents, storage media
- Desk space for paperwork
- Space for System expansion as contemplated in Section 3.6.

14.2 Architectural and Design Principles

The layout and design of the CCF shall reflect the following:

- Ergonomic principles / human factors design to conform to local labor codes and regulations
- Raised flooring to permit underfloor cables
- Removable tiles with a surface suitable for computer room installation
- Finished floor to finished ceiling height of at least 3.0 m
- Controlled access doors
- Dimmer circuits to allow variation of allumination
- At least four separate lighting zones to permit customized settings
- Two operator positions are such that any function available to one is equally available to the other
- Operators need to be able to communicate verbally
- No barriers between operators and supervisor
- Printers accessible to operators but housed in noise-suppression enclosures
- Bank of CCTV monitors elevated above desk level to facilitate viewing by operators.

14.3 Control Room Equipment Requirements

14.3.1 Radio System

Both operating positions in the Central Control Room shall have a control panel which permits selection of any of the radio channels assigned to the System. Each of the panels shall indicate the status of the radio system and state of the push-to-talk switch

All audio communication at each Console position - radio and telephone - shall be recorded by recording equipment.

14.3.2 Telephone Equipment

Telephone sets provided for each of the operating positions of the CCR console shall be multi-line and equipped with a display. These telephones shall provide memory dialing for contacting emergency personnel with a single push-button and shall provide a visual indication of the presence of calls in queue on its display.

14.3.3 CCTV Equipment

A basic monitoring complex shall contain, as a minimum, two monitors per station, located at such a height and distance from the seated operators to provide reasonable detail in the picture. One CCTV monitor shall be supplied for each operator position. The control of the CCTV views on any monitor shall be possible from both operator positions. A recording and playback facility, appropriate to the operational requirements, shall be provided.

14.3.4 PA Equipment

The PA control shall include the ability to address stations and the OMSF for CCO announcements. This control shall be secondary to the local station control, which shall have priority access to the PA system.

Access to the PA system shall be via administrative telephone sets. In addition, one master PA console shall be provided to provide priority access to the PA system under emergency conditions.

14.3.5 ATC Workstations

The console shall be equipped with ATC workstations upon which the operator can display the current status of train operations. Alarms and status indications shall identify location and nature. Interface control of each Visual Display Unit (VDU) shall be via pointing device and keyboard.

14.3.6 Service Interruption

Facilities shall be incorporated, accessible from both operating positions to interrupt the service on a segment of the alignment in the event that an incident is detected which places a passenger in danger.

14.3.7 SCADA Workstations

From each SCADA workstation it shall be possible to control the supply of the traction power and ac distribution power systems as well as monitor and control station E&M systems as described in Section 13.

15 Automatic Fare Collection (AFC)

The following section defined traditional system of fare collection. New technologies may be specified at the discretion of the client.

Where new technologies are to be introduced, the Contractor shall ensure that the validation program provides appropriate testing and validation methods to demonstrate suitability and compliance to the reliability, availability, maintainability, and safety requirements.

The Automatic Fare Collection Subsystem shall be designed to function properly under the environmental conditions specified in Section 6.1. Its design shall consider external environmental influences, such as electrical power supply, temperature, humidity, lightning, etc., together with its interface with other subsystems and “human factors”. The equipment shall be ergonomically designed in order to promote ease of use for passengers and staff (operations and maintenance). The design shall be adjusted to the anthropometric and demographic profiles present in the area.

The proposed subsystem shall be based on single-use magnetic tickets or contactless radio frequency (RF) tokens and multiple-ride, stored-value contactless smart cards (CSCs). Single-ride tickets shall not be encoded prior to issue and shall be sold from either staffed booths at the stations or ticket vending machines at the stations. The subsystem shall be a “closed” system where each passenger shall be checked at two points (entrance and exit).

15.1 Automatic Fare Collection Equipment

Each passenger station shall be equipped with the following equipment:

- Single Direction and Reversible Gates
- Special Gate
- Ticket Vending Machines (TVM)
- Ticket Office Machines (TOM)
- Station Computer.

In addition to the station equipment, the following equipment shall be provided:

- Central Master Station (Central Processing Computer)
- Fare Tickets.

The equipment housings shall be designed for security, robustness, and extended life. They shall be primarily of a metal construction and only where there is a specific requirement for other materials shall an alternative be used. The carcass, housing and outside finishes of the equipment shall be manufactured primarily of stainless steel.

AFC equipment quantities shall be provided in accordance with Section 15.1.7.

15.1.1 Single Direction, Reversible Fare Gates, and Special Gates

The single direction and reversible fare gates shall be designed to meet the goals of speed, effectiveness, and reliability. Sensors within the gate shall be provided for fraud detection.

Gates shall accommodate both single fare tickets and CSCs. If magnetic single fare tickets are provided, a conventional ticket transport mechanism shall be provided within the gates to accept and validate the paper single-ride tickets. If RF tokens are used for single fares, the token shall be presented to the gate mounted CSC reader on entry and deposited into a slot on exit gates to capture the token. CSCs shall be validated by an RF 'target' area located on the top of the gates. The CSCs are 'passed over' the target in order to validate them and deduct value as required.

In addition, every station shall be equipped with a manually released gate located adjacent to the ticket booth. The minimum clear opening width of the gate shall be 1.1 m in order to allow 'mobility impaired' passengers unhindered passage. Opening of the gate will be controlled from the ticket booth.

15.1.2 Ticket Transport Mechanism within Fare Gate

The fare gates shall include mechanisms to:

- Read data from the ticket to determine the ticket/cards validity
- Update new data to the ticket and verify new information
- Determine if the verification is successful at an entry gate and if so, return the card to the passenger at an exit slot (for magnetic single-ride tickets only)
- Determine if insufficient fare is available at either an entry or exit gate and if so, return the ticket to the passenger at the entry slot with an informational message displayed informing them to go to the ticket booth (for magnetic single-ride tickets only)
- Determine if sufficient fare is available at an exit gate and if so retain and store the ticket or RF token in a ticket stack/magazine within the gate.

If the verification of a magnetic single ride tickets remains unsuccessful after different read/write actions, the card shall be returned to the passenger with an information message displayed informing them to go to the ticket booth (for paper single-ride tickets).

CSCs are not 'inserted' into the gates and are, therefore, never retained. Messages for CSCs shall be as for the magnetic single-ride tickets.

15.1.3 Ticket Vending Machines (TVM)

The TVMs shall accept a selection of both coins and banknotes. They shall have the capability to display a variety of zone maps and/or tables.

TVM's shall issue single-use paper tickets valid for single journeys and may be configured to issue a multiple number of single-ride paper tickets.

15.1.4 Ticket Office Machine (TOM)

The TOM shall consist of the following equipment:

- Ticket Reader/Encoder for Issuing/Updating Tickets
- Target for re-valuing CSCs
- Configured Cash Register
- Coded Cash Drawer with each Register
- Excess Fare Ticket Analyzer/Dispenser Subsystem
- Ticket Revalidating Mechanism.

The ticket issuer shall only issue single-use, single-ride paper tickets and shall be based on a standard ticket-encoder unit as fitted to the gates/ticket vending equipment. It shall be operated by the Ticket Inspector's keyboard and controlled by the station computer.

15.1.5 Station Computer Subsystem

The main functions of the Station Computer shall include:

- Receiving operating parameters, fare tables, and blocked list files from the Central Processing Computer and distribute these to the equipment under its control
- Receiving traffic and sales transaction data from the equipment under its control and transmit the data to the Central Processing Computer
- Monitoring the operation of fare gates and monitor the 'fault status' for loss of communications, ticket jams, magazine full, and blocked list ticket use
- Monitoring the operation of TVMs and monitor the 'fault status' for loss of communications, ticket jams, successive failures, empty ticket rolls, coin and note vaults full, change-giving status, intrusion, and access by maintenance staff
- Monitoring the operation of TOMs and all machines for loss of communications
- Maintaining a log of alarms and events related to machine monitoring
- uploading alarms to the Central Processing Computer.

15.1.6 Central Processing Computer

The main functions of the Central Processing Computer subsystem shall include:

- Maintaining, updating and activating the list and identification of AFC equipment
- Maintaining, updating and distributing fare tables, blocked lists and other AFC operating parameters
- Maintaining, updating and distributing the list of maintenance and operating staff authorized to access AFC equipment and to hold, protect and distribute the respective personal identification numbers (PIN) for access verification
- Receiving ticket-usage and ticket-sales transaction data from Station Computers and updating the appropriate database accordingly
- Examining stored-value ticket usage transactions for possible inconsistencies and fraudulent revaluation and generating appropriate blocked list entries
- Maintaining and updating a database for stored-value tickets with a separate account for each ticket to monitor its remaining value
- Receiving equipment fault reports on passenger loads, ticket sales, and revenue collected
- Generating daily, weekly, and monthly maintenance reports on equipment failures, maintenance actions and equipment time lost
- Generating ad-hoc traffic and revenue reports based on user-selected criteria
- Synchronising the calendars and clocks with the Station Computers

- Controlling the start and end of the operating day for revenue and passenger transaction data processing
- Providing auditing facilities to check and verify ticket sales and revenue data.

15.1.7 AFC Equipment Quantity Requirements

A sufficient quantity of TVMs and fare gates shall be provided to meet the following requirements:

The maximum peak conditions at each station are as defined in

a) The AFC system shall be designed to support a passenger surge demand of 25 % above these maximum peak conditions.

b) The TVMs shall be able to clear 95 % of transactions (including queuing time and average transaction time) within three minutes under maximum peak conditions + 25 % (considering expected utilization of the TVMs and various fare types).

c) Gates shall be able to clear 95% of transactions (including queuing and transaction times) within 60 seconds under maximum peak conditions +25 %.

d) It shall be assumed that the TVM utilization rate shall be 30 %, that is, 30 % of all passengers entering a station will require the purchase of one or more tickets/tokens from the TVMs. The balance of the passengers will either hold a valid multi-ride CSC or have their ticket/token purchased by another passenger.

e) The quantity of TVMs shall be sized so that AFC system performance criterion is met with one TVM per station out of service.

f) An average TVM processing time of 40 seconds shall be assumed in the equipment quantity calculations. Exit gates shall be assumed to process one passenger every second and entry gates shall be assumed to process one person every two seconds on average.

g) There shall be one TOM per station.

15.2 Communication Subsystem

Two communication subsystems shall exist in the network, one at the station level and the other at the connection with the Central Processing Computer. When communication problems arise, an alarm shall be generated. The TVMs, TOMs and fare gates shall continue functioning normally and collecting data, however no data shall be transferred. The data shall be stored in the memory of the units and transferred after the link has been re-established.

15.3 Power Supplies

Every TVM and TOM unit shall be protected by an internal battery back-up that shall allow, as a minimum, that the ongoing transaction can be finished. In addition, all AFC equipment shall be backed-up from the station UPS equipment in accordance with Section 10.5.1.

16 Guideway Alignment

This section covers the design criteria for the alignment and related construction. All designs provided under this specification shall comply with relevant international, regional, and local codes and requirements.

The design and construction teams shall verify the deflections during design, fabrication, installation, and system operation to minimize deviations from the alignment design and the Rolling Stock specified tolerance limits.

There need to be feedback loops between construction and design teams to monitor compliance or implement changes as needed.

16.1 Clearance Requirements

The guideway shall be designed and installed so that all non-system equipment and structures always remain outside the vehicle clearance envelope, including structural deflections of guideway beams. The worst-case conditions include, but are not limited to, suspension failures, tire wear, construction and maintenance tolerances for Guide Beam surfaces, vehicle overhang on curves and super elevations, or combinations thereof. The clearance distance to adjacent structures, appurtenances, stations, or station platform doors shall include dimensional variances in the structural member or appurtenance, construction tolerances from the designed position, and the effects of chord construction techniques relative to a curved alignment. The vehicle clearance envelope includes the space occupied by the dynamic outline of the transit vehicle under worst-case conditions plus a running clearance plus a construction tolerance as needed. The running clearance is a minimum of 100 mm to structural elements, 50 mm to wayside equipment or walkway structures, or as required by the system supplier, or Client requirements. The construction tolerance is a minimum of 50 mm to non-wayside equipment or walkway structures.

16.2 Guideway Alignment

The guideway alignment is based on the alignment data given in Section 3.5.1 and the more detailed references given in Section 27. Adjustments may be required and will be considered on a case-by-case basis. When considering alterations to the alignment, primary consideration will be given to safety, passenger comfort, aesthetics, and functional design.

The ride quality cited in Sections 9.6.3 is the cumulative result of vehicle dynamics, alignment design criteria, construction tolerances, and maintenance tolerances. The following sections provide the minimum design criteria for the alignment.

16.2.1 Horizontal Alignment

The horizontal alignment shall consist of tangents joined to circular curves by spiral transition curves. In station areas, curved guideway beams should be avoided, unless allowed by System Supplier. Spiral curves shall also be used to transition between compound curves. In station areas, curved guideway is prohibited. The guideway shall become tangent 12 m prior to the platform edge, preventing intrusion into the platform gap/envelope. Transition spirals are not required in areas not in passenger service.

Circular curves shall be super elevated as described in Section 20.3.1., unless prohibited by lateral clearances or switch locations. Curve radii and spiral lengths shall be adjusted to allow the highest speed possible, and maximum super elevation applied, consistent with other requirements. The preferred minimum Mainline radius shall be 90 m, however in especially difficult situations this minimum radius may be reduced. Spiral transitions shall be used at the entrances and exits of all Mainline circular curves. Spiral length shall limit lateral jerk to the requirements of Section 20.3.1.

16.2.2 Vertical Alignment

Vertical alignment shall consist of tangents joined by equal tangent parabolic curves having a constant rate of change of grade. The maximum grade is 6.0% on the Mainline. The maximum grade through stations areas is 0.5 %.

Vertical curves shall be designed to limit the total vertical component of forces as described in Section 20.3.1.

A minimum vertical clearance of 5.5 m shall be maintained between all points on the to-be- constructed guideway superstructure and all streets, highways, and shoulders below or as indicated by local authorities having jurisdiction.

16.2.3 Alignment Aesthetics

Unless otherwise agreed with the Client, the following provisions shall apply:

To avoid the appearance of kinks, the minimum length of circular curves at the end of long tangents shall satisfy the following formula:

Length of Curve (m) > Radius of Curve (m) / 11.5.

The longer radius of a compound curve shall not be more than 50% greater than the shorter radius. Broken-back curves (any pair of circular curves in the same direction, without spiral transitions) shall be separated by a tangent not shorter than 305 m. Except in locations where train speed and structural/material considerations require, or as approved by the client, longer-radius curves or compound curves shall be used instead of broken-back curves. Broken-back vertical curves and short horizontal curves at sags and crests of vertical curves shall not be used unless approved by the client.

16.2.4 Pier Placement

Pier (or column) placement will be restricted by such factors as clearances to roadways, sight distances, street and lane widths, medians, driveways, curb cuts, existing and proposed building facades, and underground utilities. Typical standard span lengths may range from 24 – 36 m; however, the Contractor shall examine the proposed alignment to determine locations where shorter or longer spans may be required. Certain locations may dictate combining guideway support with other structures. It shall be the Contractor's responsibility to identify pier locations and coordinate with all affected parties.

16.3 Miscellaneous Topics

The Contractor shall consider and present explanations of the following at a design review:

- Urban Design Factors
- Pier Spacing, Location and Size Constraints

- Traffic Signals, Graphics and Signage
- Streets and Highways
- Sight Distance Criteria
- Traffic Control
- Pedestrian Circulation
- Utilities
- Environmental Compliance/Advantages.

17 Guideway Elements and Equipment

This section provides the requirements for the design, supply, installation and / or construction of guideway elements and equipment to be provided by the Contractor. Other guideway requirements relating in particular to the alignment are described in Section 16 and relating to the structural requirements in Section 20.

The Contractor shall ensure that:

- Guideway elements, guideway equipment and vehicle loads do not overstress the guideway structure and foundations
- All Contractor-provided guideway structures and equipment shall be correctly designed for their functions and structural loads
- All design for the guideway structure and equipment and elements shall be properly coordinated
- Construction and installation shall be undertaken efficiently.

The guideway equipment shall not impede necessary access to the guideway, other guideway equipment or the emergency walkway.

To the extent possible, and in accordance with safety and operational requirements, guideway elements and equipment that requires testing, servicing, adjusting, removal, replacement, or repair shall be designed for accessibility by:

- Locating items requiring visual inspection so that they can be directly viewed without removal of obstacles or other components
- Locating components requiring maintenance in such a manner as to provide direct access without removal of other components.

The design and installation techniques used for guideway-mounted equipment shall allow for field adjustments necessary to maintain the proper tolerances for System performance.

17.1 Guideway Structural Criteria

The guideway elements and equipment shall be designed to the structural requirements in Section 20.

17.2 End-of-Line Over-travel Buffer

The end-of-line over-travel buffer shall be designed to withstand a collision of the maximum length train with the end-of-track over-travel protection device (buffer) at the maximum impact speed attainable at the buffer in Recovery Manual Mode (RMM). Such a collision shall cause only cosmetic or readily repairable damage to the train. This requirement shall be met under any realistic loading condition expected at that location on the alignment.

The vehicle/train, under any possible loading condition or train configuration, including pushing or towing another train or being pushed or towed by another train shall not leave the guideway during collision with the over-travel protection device for speeds at which the train can be driven in Recovery Manual Mode (RMM)

In the OMSF, means shall be provided at every guideway terminus to stop and retain one AW0-loaded ultimate-length train traveling at the maximum speed at which a train can be manually operated in the OMSF.

17.3 Wayside Equipment

The Contractor shall provide any required cable trays, wireways, conduits and equipment enclosures to be mounted along the guideway for power distribution, command, control and communication, or other subsystems.

17.4 Guideway Switches

Guideway switches shall be provided and installed by the Contractor to enable the System to operate as required in

System Operating Criteria. Switches also are required in conjunction with the operation of the OMSF. The Contractor shall submit proposed switch locations and switch operations, reliability and design information for review and approval in accordance with Section 26.

17.4.1 General Switching Requirements

Switching shall be performed by in-guideway equipment.

It shall be possible to operate trains through all switches in either travel direction.

Switch running and guidance surfaces shall conform to the requirements in Section 20.3.1. Spiral transitions are not mandatory for switches provided that the reliability and ride comfort requirements are met. Speed reduction is permissible while traversing switches, provided travel time requirements are satisfied.

Switch status indication shall be provided at the CCF for all switches in the System.

Switch operation, including speed of movement and reliability, shall meet the System operational and service availability requirements. The Contractor shall provide switches that permit System operation in all environmental conditions of

System Environmental Design Criteria.

17.4.2 Switch Mechanisms and Interlocks

The required functionality for the ATP system and the switch control system to ensure safe System operation is described in Section 0. The design of the switch control system shall be in accordance with the safety principles of Section 0.

Switches that operate during any of the System's operating modes or during the transition between two operating modes shall be automatic and subject to the ATP requirements of Section 0 Power-actuated switch mechanisms shall be designed so that any noise they produce is not intrusive, and is within the limits for wayside noise defined in Section 6.3.1.

17.5 Aesthetics, Protection and Drainage

Guideway equipment, walkways, conduits, wiring, signage, and other items along the guideway shall be designed and installed to present a visually appealing, non-cluttered appearance. Such equipment shall, to the maximum extent possible, be hidden from view from below and along the sides of the guideway and shall be designed to match the guideway aesthetically.

Guideway equipment designs shall minimize surface joint conditions. Connections shall be detailed to minimize the accumulation of water and debris. Surfaces shall be caulked with an appropriate and compatible material to seal out moisture and air. Round or tube-type steel sections with continuous seal welds shall be used instead of channel or wide flange sections whenever possible and economically feasible. Edges of steel members shall be rounded to a 1.5 mm radius curve or greater.

Guideway equipment that requires painting for corrosion or other protection, or for aesthetic reasons, shall be painted a color that harmonizes with the guideway. Nuts, bolts, washers, screws, and connectors shall be corrosion protected. Dissimilar metals shall be insulated to avoid galvanic corrosion. Galvanized concrete inserts need to be made compatible with the threads of bolts furnished by other suppliers, to allow for early testing of the interface.
Guideway equipment shall allow moisture to drain from its surfaces and shall not impede or restrict the drainage flow patterns established in the basic design of the guideway.

Corrosion protection systems such as hot-dip galvanization, metalizing, zinc flake coating, and others, can be considered once appropriate testing confirms the durability of the components, like as salt spray tests or others.

17.6 Emergency Walkway

The Contractor shall design, provide, and install an emergency walkway along the entire length of the guideway compliant with International Transportation Fire Codes requirements. Deviations need to be approved by the Owner / Operator and Civil Defense / Fire Departments with jurisdiction over the system, if applicable.

Access to stations and other egress points shall be controlled. The emergency walkway shall be insulated from power rails and other guideway power and shall not present an electrical safety hazard. The walkway shall not intrude into the vehicle/train dynamic envelope.

An emergency evacuation path shall be provided at switch areas and other guideway elements that could act as barriers. Walkways where users are exposed to a hazard of falling 1.2 m or more shall be equipped with guardrail on each side of the walkway where the hazard of falling exists.

A walkway without a handrail shall be at least 1,120 mm wide; one with a handrail shall be at least 700 mm wide. Walkways where users are exposed to a hazard of falling 1.2 m or more shall be equipped with guardrail on each side of the walkway where the hazard of falling exists. The dynamic outline of vehicles operating along the adjacent guideway(s) shall leave a clear width above the emergency walkway of at least 610 mm measured at a point 2 m above the walking surface. The walkway shall not be higher than the vehicle floor threshold plus 25 mm, or more than 1.2 m below the vehicle floor threshold under both normal and worst-case vehicle suspension failure conditions. During the design process efforts shall be made to reduce the vehicle floor to top of walkway distance or provide means of evacuation. The gap between the vehicle emergency door threshold and the emergency walkway shall be minimized while accommodating the vehicle clearance envelope. The minimum clearance required from the vehicle dynamic envelope to the walkway structure shall be no less than 50 mm.

The emergency walkway shall provide visual indications to passengers on the walkway defining the location of the walkway edge adjacent to the guideway and directing passengers to the nearest evacuation point. Emergency lighting shall be provided by the Contractor. The egress route shall have a level of illumination of no less than 2.7 lux.

17.7 Signage

The Contractor shall provide all signage along the guideway for the following functions:

- Emergency evacuation safety and information
- Other passenger and O&M personnel safety and warning
- Maintenance and manual vehicle operation, such as power zone and ATC block boundaries (if used), station stopping points and switch zones.

Proposed signage shall be submitted to the Client for approval in accordance with the Data Submittal Schedule.

17.8 Expansion Joints

The expansion joints are one of the most critical components of the civil guideway, because of the dynamic impacts and wear from the friction of the rolling stock. Any equipment or hardware which is mounted to the guideway, and which is typically under cyclic loading must be installed in such a manner as to ensure that all fasteners are correctly pretensioned and that mounting interface surfaces are sufficiently flat to avoid any loss of fastener preload.

The design documents need to specify fabrication tolerance and flatness criteria of the base and finger plates, an assembly tolerance after installation on-site, as well as consider the presence of surface protection.

Depending on the type of structural concept, the side movement of top expansion joints needs to be considered in the design of the finger plates, avoiding the risk of lateral loads on fingers if they have not been designed to take such loads.

When using carbon steel for the expansion joints, the surface treatment shall be hot dip galvanized, or other systems to achieve the specified usable life. It's recommended to study the effect of wear on the top plate due to the rolling stock to assure the durability of this plate without corrosion.

Base plates need to incorporate burp holes to ensure that there are no voids under them when the structure is concreted, creating issues during operations.

The corrosion protection of the bolts of the expansion joints needs to be addressed. There needs to be a study of the fixation that indicates the method to reach the pretension force required to ensure the long-term fatigue life of the joint bolt. Depending on the surface protection, the study needs to analyze the impact of the surface treatment on the torque of bolts. Fatigue studies and testing of the bolts and assemblies are necessary because of the repetitive efforts.

18 Stations and Station Equipment

The Contractor shall design and construct passenger stations and design and provide all station-related equipment necessary for passenger handling and for train operations at stations in accordance with applicable international, national, and local codes and standards.

The Contractor's design shall meet the following design objectives:

- Station site layouts shall be designated to facilitate convenient, direct, and safe access to station entrances
- Urban design factors shall be taken into account. Station designs shall balance architectural treatments and other aesthetic considerations with structural efficiency
- Station site layouts shall be designed to be responsive to the physical character of specific locations and shall minimize negative impacts on adjacent structures and land uses
- Stations shall have a consistent, System-wide design with an identifiable image. Functional similarity shall be maintained. System components are to be used in a consistent manner to provide legibility and functional clarity
- Station design shall provide clear patron circulation and ease of movement within the station
- Stations shall present an inviting physical and visual environment for patrons while ensuring the station materials and construction assemblies are durable, low maintenance, and vandal-resistant
- Public areas exposed to the elements shall provide areas of protection while maintaining a high degree of openness for visual security and natural ventilation
- The Contractor shall provide:
- Station finishing and entrance/ancillary structures, including mechanical, ventilation as applicable, electrical and lighting system
- Elevators and escalators System-side
- AFC equipment System-wide
- Signage and graphics System-wide.

The Contractor shall be responsible for all necessary coordination required for design and construction, including station design approval.

18.1 Station and Platform Sizing

The stations shall as a minimum be able to accommodate the System configuration, capacities and operations specified in Section 3.5. In particular, stations shall be sized to meet the station maximum boarding and alighting requirement in Table 3-3 and Table 3-4. Platform lengths shall as a minimum be long enough for the maximum train length required by the requirements of Section 3.5.

Station and platform sizing shall conform to a suitable international standard as well as applicable local codes.

Stations and platforms shall be expandable to meet the System expandability considerations in Section 3.6.

18.2 Station Components and Equipment

The Contractor shall design, furnish, and install station components and equipment as set forth in this section to meet the System service and operation requirements in Section 50.

18.2.1 Station Platform Edge Safety

The Contractor shall design, furnish, and install, test and commission all platform edge safety devices as required by this section.

18.2.1.1 General

This section sets out the requirements for the station platform safety systems. These systems protect passengers on a platform against the hazards of moving trains. They include a Platform Screen Door/Barrier System.

For all stations, the Contractor shall design, supply, and construct a Platform Screen Door/Barrier System (PSDS) along the length of each platform edge. This system shall isolate the platform from the guideway and shall provide a barrier against passenger access to the guideway when a train is not stopped at the station. The system shall include automatically controlled platform sliding doors, emergency platform doors as required, and emergency walkway access doors/gates.

A means shall be provided to allow egress from a misaligned train onto the station platform. Where auxiliary egress doors or gates are used, a latching mechanism shall be provided on the guideway side to allow passengers to exit onto the platform.

18.2.2 Platform Screen Door/Barrier System

18.2.2.1 Safety and Performance Requirements

Passenger safety shall be the prime consideration in the design and construction of the Platform Screen Door/Barrier System (PSDS). In particular, automatic door control and monitoring shall operate in a safety critical manner.

When a train is stopped at a platform, the platform sliding doors/gates and the corresponding train doors shall automatically open, under the control of the ATC system or other SIL 4 (Safety Integrity Level 4), only if the train doors are properly aligned with the platform doors/gates. The acceptable stopping point tolerance within which the platform and vehicle doors may be automatically opened shall be +/- 0.8 m. The platform sliding door opening width shall take this stopping accuracy into account, to ensure a clear opening width is large enough to accommodate a wheelchair, when the vehicle stops and opens its doors at the stations. The target stopping accuracy of +/- 0.25 m shall be achieved for 99.0 % of all station stops. The gap between the platform doors and the vehicle doors shall be less or equal to 130 mm to ensure that no person is trapped as the doors are closed.

If an arriving train is of a size less than the maximum train consist for which the screen door/gate system is designed, only those platform sliding doors opposite corresponding vehicle doors shall automatically open.

All platform sliding doors/gates and auxiliary egress doors shall be verified by the ATC system, in a safety critical manner, to be closed and locked before a train may be allowed to leave a station under automatic control.

A platform sliding door/gate may not open automatically unless a corresponding vehicle door is present.

The closed and locked status of all platform doors/gates shall be continuously monitored by the ATC system. If either of these signals is not present, the ATC system shall immediately and automatically stop all train movement on the track adjacent to the platform, and an alarm shall be triggered at the CCF.

The platform sliding doors/gates shall not exert a closing force greater than 156 N and a closing kinetic energy greater than 9.5 J. The opening and closing speeds shall conform to the vehicle door speeds within +/-20 % and the opening/closing speeds of each door set shall be capable of individual adjustment.

The platform sliding doors/gates shall include an obstacle detection system that conforms to the same requirements as for the vehicle doors in accordance with Section 9.10. If an obstacle is detected by a platform sliding door/gate, the corresponding vehicle door shall also re-open. If an obstacle is detected by a vehicle door, the corresponding platform sliding door/gate shall also re-open.

In the event of a power failure, all platform sliding doors/gates shall operate with power from the UPS system under normal operating mode for a minimum of one hour.

For each platform sliding door/gate set, a three-position key switch shall be installed into the platform screen adjacent to the door or inside the mechanism enclosure above the door. The key switch shall function as follows:

- The centre position shall be the normal position for automatic control
- In the left position, the key shall be removable and the door/gate set shall remain closed, locked and inoperative ("locked-out") with no effect on the operation of the other door sets on that platform side
- In the right position, the key shall not be removable and the door/gate set shall open and remain open as long as the key switch remains in that position.

The Contractor shall install a local control panel for each platform side (two per station). The panel shall be installed on the platform in such a fashion so as to allow a technician at the panel to view the corresponding door/gate sets. The panel shall include a local/remote key switch. When in the local position, an alarm shall be triggered at the CCF indicating that the doors are under local control. As a minimum, the following panel functions shall be available:

- Open/close selected door/gate sets
- Override lack of close/lock signal from doors/gates (to allow train operations to continue following a door failure)
- Lamps showing the status of the door/gates closed/locked/open/override signals.

As an alternative to the above-described local control panel, the Contractor may install an individual override switch, and status lamps, inside the mechanism enclosure above each door/gate.

On the track side of each platform sliding door/gate set, means shall be provided for passengers to manually unlock and open the door so as to gain access to the platform.

It shall be possible for authorized persons on the platform side to manually open the doors/gates, using a key.

It shall be possible for passengers on the track side of the PSDS to manually unlock and open any emergency platform door or emergency walkway access door. It shall be possible for authorized persons on the platform side of the PSDS to unlock and open these doors using a key.

All platform emergency doors/gates and emergency walkway access doors/gates shall be monitored at the CCF. An alarm shall be triggered at any time one of these doors is opened.

18.2.2.2 PSDS Design Requirements

Each PSDS installation shall provide a suitable height barrier along the length of the platform and shall be positioned in accordance with the typical station reference drawings, not shorter than 1100 mm. At the extreme ends of the platform, the PSDS shall include returns of sufficient length and height to close the gap between the platform edge and the station end walls/barrier or railings.

Each PSDS installation shall include a sufficient number of platform sliding door/gate sets (one set per train door) to accommodate the maximum length train. The PSDS system shall accommodate future expansion of the System envisioned in Sections 3.6 and 18.1 This typically means supply and installation of sliding and emergency doors along the length of the platform, but equipping (door/gate operator, etc.) only on the doors that would be active in the initial System. Each platform sliding door/gate set shall have an opening width at least as large as a vehicle door set. The platform sliding doors/gates shall be positioned sufficiently close to the platform edge to ensure that no person could be trapped between a vehicle and the doors when the doors are closed.

The Contractor shall make provisions for evacuating passengers from a train that has stopped at any point along the platform outside of the normal stopping range. If necessary, emergency platform doors/gates shall be installed between adjacent platform sliding door sets and/or at other locations along the platform edge. Doors/gates shall also be installed in the PSDS returns to allow for access to the emergency walkway.

The PSDS shall be constructed of robust, low maintenance and easily cleaned sections, stiffened horizontally and suitable for local environmental conditions.

The platform sliding doors shall be supported on an overhead track or be self-supporting. The overhead track (if used), and mechanism shall be protected from the elements by fixed fascia panels on the track, top and bottom sides. Lockable, hinged fascia panels shall be installed on the platform side for access for servicing and maintenance.

The door threshold shall be flush with the platform floor finished surface. The thresholds shall be long wearing, non-skid and readily cleanable. The Contractor shall coordinate all the interfaces to ensure that provisions for the thresholds (e. g. blockouts, drainage, etc.) are made in the design of the stations.

The screens and doors/gates shall withstand at least a cyclic pressure of +/- 500 N/m^2.

The screens and doors/gates shall withstand a crowd pressure applied at 1 m above floor level of 500 N / linear meter of PSDS door width without deterioration, and of 1,500 N / linear meter without rupture.

The Contractor shall coordinate the grounding/insulating interfaces.

The design and construction of the platform sliding doors/gates shall enable regular, reliable operation to be achieved for at least 25 years.

It shall be possible to carry out most preventive maintenance operations with the doors/gates in place.

18.2.3 Station and End Emergency Doors

There shall be door(s) at each end of each station platform for access from the guideway emergency walkway. Doors shall be durable and low maintenance. The platform end doors shall have both local and remote alarms. Provision for key de-activation of the local alarm by authorized personnel after clearance from the CCF shall be provided.

It shall be possible for authorized personnel possessing the appropriate key to open the platform end doors. Passengers shall be able to open the end doors from the emergency walkway by means of an emergency release mechanism located on the door.

Platform end doors shall be self-closing and latching so that they cannot be inadvertently left open.

Station platform edge doors shall be located along each edge of the station platforms, including active passenger access doors and passive emergency egress doors. Except for normal passenger access to the monorail trains, opening any station platform edge door shall result in an alarm being sent to the CCF. If any platform edge door is unlocked and/or open without CCO authorization, trains shall be prohibited from entering or leaving that station. If any such door is unlocked without CCO authorization after a train has entered the station area, the train shall stop immediately using emergency brakes. Resetting of the emergency brakes by CCO shall be permitted only after positive confirmation from security personnel.

18.2.4 Blue Light Station / Emergency Guideway Power Shut-Off Switch

A Blue Light Station for emergency guideway power shut-off shall be located adjacent to each platform emergency door zone as required by NFPA-130. A service telephone shall be located next to this switch in a weather- and vandal-resistant enclosure.

All exposed surfaces on the emergency guideway power shut-off switch shall be weather- and corrosion-resistant, and designed, furnished, and installed by the Contractor.

18.2.5 Station Passenger Information

The Contractor shall provide static station signage, and a public address system capable of generating automatic audio announcements of train arrival/departure. These signs and audio announcement subsystems shall provide sufficient visual and audible information to passengers to guide them in the correct and efficient use of the System.

The Contractor shall prepare a signage and graphics plan (excluding advertising) and submit it to the Client for information.

18.2.5.1 Station Signage

All signs in public and non-public areas of each station including emergency instructions and others required by this shall be provided by the Contractor.

Signage shall be provided for the following:

- Station identification (at entrances)
- Fare paid zones
- Patron routes to.platforms
- Station identification (platforms)

- System use instructions
- System Map
- Services (e.g., public and emergency telephones, toilets, etc.)
- Elevator/escalator/stair directives
- Exit routes
- Emergency routes
- Handicapped routes
- No smoking
- Entry/use restrictions
- Emergency equipment.

Signage requirements at station sites will vary and will be determined by neighboring facilities, surrounding traffic patterns and uses.

18.2.5.2 Station Arrival/Departure Announcements

The Contractor shall supply and install station platform audio announcement devices that signal the arrival and departure of trains. The arrival announcement shall sound approximately ten (10) seconds before a train is expected to stop at a station. The departure announcement shall precede the train door closing by approximately four (4) seconds. Each platform side shall have a unique message to differentiate it from the opposite side and to indicate the direction of the train arriving or departing.

18.2.5.3 Station Dynamic Signs

A system of dynamic Passenger Information (PI) station signs shall be designed, furnished, and installed by the Contractor in each of the passenger stations. The Contractor shall also be responsible for all interfaces with the ATC, Communications or other systems required to achieve proper operation of the dynamic signs. The displays shall use LCD wide screen display technology or other display technology approved by the Client with a ruggedized enclosure that is suitable for the transit environment. The displays shall support multi-frame views of motion video clips, text-based passenger information, and dynamic text or graphics based commercial advertising.

All dynamic station signs shall be furnished and installed to provide legible and understandable messages to passengers. A minimum of one (1), double sided passenger information display shall be provided for each platform edge, located halfway along each platform, and perpendicular to the platform edge. One (1) single sided passenger information display shall be provided for each concourse area. Displays shall feature suitable size, resolution, and performance characteristics for displaying a minimum of three (3) rows of fifteen (15) characters. Display controllers and media players shall be provided to meet the functionality defined herein.

The PI displays shall mimic and be synchronized with the automatic and manually triggered PA messages as described within Section 12.1. The message content on each display shall provide passengers with information on the destination of each arriving train and shall provide special messages to indicate out of service trains, System closure or failure. Normally, message content shall be triggered by the ATS. CCOs shall be able to override the automatic messaging at any station and select from a list of pre-configured messages.

Messages displayed initially by the dynamic signs shall include all initial System operating modes and operating and station status conditions.

The station PI dynamic sign messages shall include, but not be limited to:

- The direction and major destination(s) served by each train
- The time until the next train arrival on a platform
- Train out of service or going out of service
- Clock time
- Special instructions
- Advertising.

The concourse dynamic sign messages shall include, but not be limited to:

- The general status of the System (e.g. open, closed, closing in a number of minutes, or delayed services in either direction)
- The status of the station
- The status of other stations (e.g. closed)
- Clock time
- Special instructions
- Advertising.

The dynamic sign subsystem shall include the following equipment:

- Sign units comprised of LCD elements or other display technology selected by the Client.
- All necessary electronic interfaces
- Sign housings and mountings as approved by the Client, including any associated static messages
- All control and power wiring necessary for system operation
- System design, software, fabrication, installation, test, check-out ,and demonstration.

The design of the signs and their messages shall be included in the Signage and Graphic Plan submitted to the Client for information in accordance with the Data Submittal Schedule.

18.2.6 Public Address System

The Contractor shall design, furnish, and install the public address system of Section 12.5. The public address system speakers shall be attached to and integrated within canopies or finish installations.

18.2.7 CCTV System

The Contractor shall design, furnish, and install the CCTV equipment for video surveillance as described in Section 12.3. The CCTV cameras shall be attached to and integrated within canopies or finish installations.

18.2.8 Emergency Telephones

The Contractor shall design, furnish, and install the emergency telephones described in Section 12.4. The emergency telephones in station areas shall be attached to and integrated within station walls or finish installations or in stainless steel, vandal- and weather-resistant boxes. The Contractor shall furnish and install all conduit, wiring and connections for emergency telephones.

18.2.9 Fire/Smoke Detectors and Alarms

The Contractor shall design, furnish, and install a fire/smoke detection and alarm system in each enclosed area of each station, including equipment rooms. Within public areas of each station, fire/smoke detectors and alarms shall be attached to and integrated within canopies or finish installations. The Contractor shall furnish and install all conduit, wiring and connections for fire/smoke detection and alarm components in stations.

18.2.10 Door Alarms and Security Equipment

All doors between public and non-public areas shall have locks meeting the requirements of Section 7.2 Intrusion alarms shall be provided by the Contractor in accordance with Section 7.2. All exterior doors and normal public entrance gates shall have such locks and alarms.

18.2.11 Station UPS Equipment

The Contractor shall design, furnish, and install the station Uninterruptible Power Supply (UPS) equipment and components specified in Section 10.6.

18.2.12 Fire Management System and Panel

The Contractor shall design, furnish, and install a fire management system and panel at each station in accordance with the local fire regulations. This fire management system and panel shall meet the requirements of Section 0. The fire management panel shall be located at the ground level, adjacent to station egress or access point as coordinated with the local fire officials. It shall be attached to and integrated within the wall or finish installations of the station.

18.3 Equipment Room and Enclosure Criteria

18.3.1 Communications Room

The communications equipment and racks specified in Section 12 shall be housed in in accordance with a Communication Equipment Plan.

18.3.2 Station Substation

The station substation and associated electrical power supply and distribution equipment, specified in Section 10 shall be located in the electrical equipment room in each passenger station or in accordance with a Power Supply & Distribution Plan.

18.3.3 UPS Equipment

The UPS equipment shall be located in the electrical equipment room in each passenger station.

18.3.4 Wayside Controls Equipment and Enclosures

The wayside controls, racks, enclosures, and other related equipment shall be located in the electrical equipment room in each passenger station.

18.3.5 Elevators and Escalators

Locations at the stations shall be provided to house the elevator and escalator equipment. These areas (rooms) shall comply with the requirements of the elevator/escalator equipment manufacturer and meet the applicable codes and standards.

18.4 Electrical and Lighting Components

The Contractor shall design, furnish, and install the electrical and lighting components for non-public areas and rooms and for public areas of each station to meet the following requirements in Section 18.4.1.

18.4.1 Lighting

18.4.1.1 Non-Public Areas

The minimum levels of lighting that shall be provided in non-public areas are shown in Table 18-1

Table 18-1 Minimum Levels of Illumination in Non-Public Areas

Area	Average Illumination (lux)
Station Substation Rooms	215
Communications/Wayside Control Rooms	270
Elevator Machine Rooms	215
Other Ancillary Rooms	215

18.4.1.2 Public Areas

The Contractor shall provide sufficient lighting, including power feed and panel boards, in all public areas to comply with the applicable codes and standards.

18.4.2 Emergency Lighting

An emergency lighting system, powered by the UPS, shall be provided by the Contractor. This system shall provide the applicable emergency lighting levels in accordance with NFPA 130 to all public areas of the passenger stations in the event of a failure to the primary electrical system.

18.4.3 Housekeeping Electrical Power

The Contractor shall design, furnish, and install the electrical power components necessary to operate and maintain the passenger stations.

18.5 Mechanical Components

The Contractor shall design, furnish and install all passenger station mechanical components as defined in the following subsections 18.5.1, 18.5.2, 18.5.3, 18.5.4, 18.5.5, 18.5.6, 18.5.7, 18.5.9 and in accordance with international, national and local codes and standards.

18.5.1 Drainage

A passenger station drainage system shall be designed, furnished, and installed by the Contractor to protect passengers and equipment from precipitation.

18.5.2 Water Supply

Water supply lines shall be designed, furnished, and installed by the Contractor.

18.5.3 Standpipes

Standpipes, as required to comply with the applicable codes and standards, shall be designed furnished and installed by the Contractor. This design shall be coordinated with the design of the fire detection system.

18.5.4 Mechanical Ventilation and Air Conditioning

Mechanical ventilation and heating or air conditioning shall be considered for the public and staff areas of the passenger stations. Factors influencing the decision and design shall include local climatic conditions, location of the station (elevated, at-grade or underground) and whether full height or medium height platform screen doors are selected (see section 18.2.1.1).

Mechanical ventilation and heating or air conditioning equipment necessary to maintain the operating environment for components of the System, shall be designed, furnished, and installed by the Contractor.

18.5.5 Landscaping

Landscaping damaged during construction of the System or the location of which interferes with the operation of the System shall be replaced and/or relocated in kind.

18.5.6 Escalators

Escalators, including cladding, when required, can be provided at each of the passenger stations. For centre platforms, two escalators may be furnished to to provide vertical access between each station level. If escalators are present, side platform stations may be equipped with two escalators per platform per station level. Therefore, for stations with two levels (ground and platform levels), there might be two escalators for a centre platform station and four for a side platform station. For stations with three levels (ground, mezzanine, and platform levels), there might be four escalators for centre platform stations and eight escalators for side platform stations.

18.5.7 Elevators

Elevators, including the interior and exterior finishes, shall be provided at each of the passenger stations. One elevator shall be supplied at each centre platform station to provide vertical access between different station levels. Side platform stations shall be equipped with one elevator per platform, two per station.

18.5.8 Toilet Facilities

Public toilet facilities when required, can be provided in stations, with number of fixtures selected according to predicted use and demographics, following the station boarding and alighting pattern of Section 3.5.4. If public toilets are provided, the toilets shall contain accessible toilets and infant change tables.

18.5.9 Station Canopy

Each station shall be provided with a weather protection canopy for all areas accessible to patrons while in the station. The Contractor's design shall meet the following objectives:

- Lightweight, durable, and low maintenance materials
- Easily adaptable to each station condition
- Be visually interesting and distinctive; the canopies are a key element in providing a consistent, identifiable System-wide image.

19 Operations, Maintenance and Storage Facility (OSMF) and Equipment

This section addresses the requirements for the Operations, Maintenance and Storage Facility (OMSF) and equipment. The OMSF shall be designed, constructed and equipped by the Contractor to facilitate the maintenance of the System and the storage of the Total Fleet as specified in Section 3.5.3. Spare equipment, parts and consumables shall be supplied and stored at the OMSF, which shall be the location of all on-site repair and maintenance required by the train fleet and other System facilities and equipment. Provisions shall be made for all functions and areas required by this section.

Maintenance equipment shall be provided by the Contractor for inventory control, maintenance scheduling, maintenance management information processing, servicing, cleaning, inspection, troubleshooting and repair of all System equipment. Equipment need not be supplied for maintenance tasks to be done by off-site Contractors or workshops. This shall include all maintenance of computer systems, test equipment, equipment test fixtures, and standard and special tools. In addition, the Contractor shall provide equipment for inventory storage and handling of all materials and spare parts.

System maintenance shall be carried out in accordance with the Contractor's Maintenance Plan and Maintenance Manuals.

19.1 Functional Requirements

The functions of the OMSF are associated with train storage and System maintenance.

19.1.1 Train Storage and Operations Interface

Trains may be stored at station locations or in the OMSF when not required for service. Trains shall normally be stored in the automatic mode so that it is not necessary to initiate automatic operation before entry into service. Prior to the beginning of daily operations, or when additional trains are needed for operations, the trains shall be entered into service automatically from online storage in stations or from the automatic storage bays in the OMSF. This procedure shall not require intervention from personnel on board the train. There shall be a transition zone between the automatic storage yard and the maintenance building, where manual operation is mandatory. Trains leaving the automated yard in UTO shall stop in the transition zone. Here a train operator shall board the train and drive it in RMM into the maintenance building. Trains leaving the maintenance building shall be driven in RMM into the transition zone, where the train operator shall alight. The train shall then be authorized to enter UTO and move into the automatic storage yard.

All trains leaving the OMSF shall enter the mainline guideway under automatic control of the train control system. Trains shall receive any required pre-operational testing prior to leaving the OMSF to enter into revenue service. Space and equipment shall be provided for these operations, including hosting of vehicles, maneuvering room, test equipment, control equipment, and all associated guideway.

At the end of the operational day, or when trains need to be removed from normal revenue service, the trains may be either stored in designated areas on the Mainline guideway or received from the mainline guideway into the OMS. At the remote command of a CCO from the CCF, trains shall be routed using pre-programmed routing to appropriate storage and maintenance positions.

19.1.2 OMSF Functional Requirements

The OMSF shall provide all architectural, structural, electrical, ATC, and other features to accommodate the following:

a) Train storage capacity, sized for the total fleet, as specified in Section 3.5.3. Guideway beams in the maintenance building may be used for train or vehicle storage when the beams are not required for maintenance.

b) Automatic operation capability from the Mainline up to the entrance of the OMSF building on all beams other than beams dedicated to maintenance or recovery vehicles.

c) Driving trains into any maintenance or storage location under their own power without the use of stingers.

d) Space and facilities shall be provided for vehicle inspection, maintenance, and interior cleaning. Daily inspections and cleaning may be carried out in stations or in the OMSF.

e) Regardless of the level of vehicle inspection, maintenance, and interior cleaning that will be performed, personnel shall be protected from hazards such as moving vehicles and propulsion power. Provisions shall be made for firefighting in any train storage or maintenance location.

f) Movement by a motorized recovery vehicle of an unpowered train and for storage of the recovery vehicles until needed.

g) Storage of any required beam-mounted maintenance or recovery vehicles and trailers. The storage location shall have direct access to the guideway.

h) The CCF and associated equipment rooms, including for train control and communications equipment.
i) Office space for staff.
j) Lockers, showers, and washroom facilities for staff.
k) Lunchroom.
l) Parking facilities: OMSF parking shall be sufficient for the O&M staff on duty in the OMSF, plus space for System Road vehicles. Space shall be provided inside the OMSF building for the loading and unloading of delivery vehicles.

19.1.3 Maintenance Functions

The maintenance functions to be performed at the OMSF shall include:

a) Service: The periodic replacement of consumables and expendables and adjustment of parts to their nominal position, required tolerance, setting, output, etc.
b) Cleaning: Interior and exterior cleaning.
c) Inspection: Periodic inspections.
d) Repair: The repair of trains and assemblies removed either from trains or from wayside equipment.
e) Maintenance Information Management and Scheduling: The processing of maintenance information, work reports, failure reports, and System performance data needed to manage the System maintenance program effectively and efficiently.

The following list is indicative of the activities involved and facilities required to perform the above functions. The Contractor shall provide all required standard and special tools, test equipment, hoists, cranes, furniture, other equipment/fixtures, consumables and expendables, and facilities needed to perform all planned System maintenance activities as follows:

a) Vehicle washing.
b) Vehicle interior cleaning.
c) Maintenance bays located in the OMSF where large assemblies including main support wheels may be easily replaced. The Contractor shall provide all equipment necessary for the testing and subsequent replacement of assemblies. The Contractor shall determine the size and configuration of these maintenance bays. Floor areas shall provide safe, well-lit, and convenient workspace for maintenance personnel.
d) At least one maintenance bay shall be suitable for maintenance and inspection of the beam-mounted System support vehicles.
e) An open floor area near these maintenance beams, with appropriate maintenance equipment.
f) Component repairs in appropriate separate shops and areas.
g) Wheel repairs.
h) Electronic assembly troubleshooting and repair in shops with appropriate HVAC.
i) Welding, metal work, and machine shop areas.
j) Vehicle HVAC maintenance, repair, servicing, and cleaning.

k) Paint booth with suitable ventilation and storage provisions for painting of small components.

l) Battery charging and storage area for maintenance and storage of revenue vehicle batteries. This area shall meet all applicable codes and if required, shall have appropriate fire suppression and ventilation devices.

m) Shipping, receiving, and inventory control system. This may be integrated with the MMIS.

n) Secure area for the storage of tools and spares equipped with appropriate storage bins, shelves, and racks, and located conveniently to the main maintenance bays.

o) Lubrication and the storage of lubricants and other flammable materials in a room with at least a two-hour fire rating.

p) Provisions for delivery and shipping of parts and equipment.

q) An appropriately sized freight elevator connecting all levels of a multi-level maintenance building. This elevator may also be used for System personnel, including access for the handicapped.

r) A utility room with appropriate plumbing for storage of supplies and equipment associated with custodial functions.

s) Offices for operations and maintenance personnel including associated data processing functions. These offices shall be located close to the maintenance area. The maintenance control office shall be on the same level as the main maintenance areas.

t) Employee locker rooms, toilet and shower facilities, break and lunchroom(s), and conference/training room(s). Separate male and female locker, toilet, and shower rooms shall be provided. There shall be toilet facilities in each separate OMSF building and on each floor of a multi-floor building.

u) All offices and other personnel rooms shall be appropriately finished and furnished. All such offices and rooms shall be accessible to handicapped employees and visitors with disabilities.

v) Adequate surface areas for employee and visitor vehicle parking and roadways connecting these parking areas with the outside road network.

Depending on the size of the system, some of the functions of rooms indicated above can be accommodated with dedicated spaces.

19.1.4 Location, Design and Finishing

The Contractor shall provide the structure, finish, all furnishings, and electrical power equipment for this facility as well as all equipment and other items required for the functions to be performed therein.

The Contractor's detailed plan to use this facility shall include finishing, furnishings, use of the immediately adjacent area, access routes, and operating and maintenance activities. These details shall be included as part of the OMSF Design Review. Information, sufficient for preliminary facility layout, design, and use, shall be provided in the Contractor's Design/Construction Interface Document.

The Contractor shall furnish operational and informational signage and graphics in the OMSF. These signs shall be shown in the Graphics Plan.

All communications equipment within the OMSF, including service telephones, public address systems, and maintenance radios and their conduit, power connections, and mountings, shall be provided by the Contractor.

19.2 OMSF Guideway and Related Equipment

The Contractor shall provide all guideway for passenger train and vehicle movement into, out of, and within the OMSF.

Guideway for the following activities shall be powered and within the ATC automatic area:

a) Train checkout and testing for entry into automatic operation.

b) Train/vehicle maintenance/storage.

c) Vehicle exterior cleaning.

d) Train/vehicle movement among (a), (b), and (c) above; the maintenance shops and the mainline guideway.

If trains are power propelled, and no stringer system is provided along maintenance bays, all maintenance and storage beams for revenue trains shall be equipped with power rails. A labeled flashing red light shall automatically be activated for each beam whenever the power rail is energized. It shall be possible to remove power from any maintenance or storage bay on an individual basis.

If building doors are provided the door status shall be indicated in the CCF. Local manual control of these doors shall be provided and installed. Trains shall be driven in RMM into/ out of the OMSF building. The Contractor shall provide all equipment necessary for handling washing fluids and/or solvents. Equipment to recapture and/or treat wash-water, including car wash water recycling, and other fluids shall also be provided. The Contractor shall provide specific information regarding the quantity and composition of the proposed effluents from washing and any other maintenance activities in the Design/Construction Interface Document.

19.3 Maintenance Tools and Equipment

The Contractor shall provide all tools, equipment, special guideway-based vehicles, and off-guideway vehicles required for pre-operations checkout, servicing, inspections, troubleshooting, maintenance, and repair of System equipment. The tools and equipment shall include the following functions and items:

a) Vehicle maintenance.

b) Train control and communication subsystems maintenance.

c) Power supply and distribution subsystem maintenance.

d) Guideway-mounted equipment maintenance.

e) Station equipment maintenance.

f) System equipment cleaning.

g) System facility cleaning.

h) Maintenance vehicles as required.

i) Equipment to lift vehicles for maintenance (as required).

j) Air compressors of sufficient power and capacity, and including associated tanks, air dryers, and piping.

k) Electronic and mechanical equipment required for diagnosis, troubleshooting, maintenance, and repair.

l) Support equipment maintenance.

m) Fuel dispensing and storage equipment.

n) Computer system hardware, software, and peripherals.

Equipment shall be provided to assist in the recovery of trains immobilized on the guideway. The nature of the equipment shall be determined by the needs of the recovery procedures.

A preliminary list of tools and equipment shall be included as part of the Design Review Submittals in accordance with Section 4.3. All necessary tools and maintenance equipment shall be supplied as part of the Contract.

19.4 Spare Parts, Expendables and Consumables

Spare parts and equipment are those items that are rotated into the fleet to allow worn and failed equipment to be removed and repaired or rebuilt, e.g., electric motors, compressors, body panels. Expendables and consumables are those items which are used or consumed in service and are not repaired, but are replaced with new items, e.g., belts, brake shoes, collector brushes, and lubricants.

The Contractor shall plan, procure, and provide required stocking levels for an inventory of spare parts and equipment, expendables, and consumables to meet all of the System requirements. The Contractor shall establish stocking levels, procurement, and supply procedures, and meet all related requirements of this section.

The following requirements shall apply to the inventory of spare parts, expendables, and consumables:

a) A sufficient stock of spare parts and equipment shall be provided to assure that, as worn or malfunctioning equipment is removed from the System, replaced with the spare items, and then repaired or re-conditioned, and the System Availability requirements are met. The Contractor shall determine the specific inventory considering cost, availability, supply process, and replacement/procurement lead times.

b) The inventory shall include sufficient expendables and consumables to operate the System on a continuing basis meeting all operating, service availability, and maintenance requirements. The expendables and consumables shall be replenished as required to ensure their availability when needed.

c) The Contractor shall maintain a list of all inventory items, categorized by subsystem or component, and listing the product or part name, Contractor’s part number and supplier’s part number, special storage requirements, three sources/manufacturers (if available), names and addresses, and current price. It shall be possible to order the list by assemblies and subassemblies to coordinate with the illustrated parts catalogues and assembly instructions of the maintenance manuals. This list shall be part of the computerized MMIS.

The Contractor shall prepare a list of spare parts, special tools and test equipment and submit it to the Client for information.

19.5 System Support Vehicles

19.5.1 On-Guideway Maintenance and Recovery Vehicle

The Contractor shall provide at least one guideway-based, Maintenance and Recovery Vehicle (beam-mounted maintenance vehicle) to:

a) Inspect and maintain the guideway and guideway equipment, and

b) Assist in the retrieval of disabled trains anywhere on the guideway.

The Contractor shall determine the number and type of beam- mounted maintenance vehicles needed and provide appropriate storage and maintenance space at the OMSF.

The following features and capabilities shall be provided in one or more types of beam mounted maintenance vehicles(s), which shall:

a) Be bi-directional with equal performance in both directions.

b) Couple with any maximum-length train, then push, pull, and stop a maximum-length AW0 train over the entire length of the guideway for an indefinite period of time, without reliance on system power rails if provided. Under failure recovery conditions, it shall be able to push or pull the maximum-length AW2-loaded train into the most convenient station, where passengers will be unloaded. While the beam-mounted maintenance vehicle shall have such push-pull capability, it shall not normally be used for such purposes.

c) Carry replacement parts for maintaining and repairing guideway and/or wayside equipment.

d) Carry equipment for vehicle/train recovery.

e) Generate compressed air and 120 Volt AC auxiliary power.

f) Have on-board storage for selected maintenance equipment and parts.

g) Be able to operate on all selections of System guideway under all environmental conditions.

h) Have on-board radio communications.

Any beam-mounted maintenance vehicle, by itself or with trailers, when loaded for any of its functions, shall not exceed the load limits established for the passenger vehicle for the guideway structure or of any guideway equipment, including guidance and running surfaces. Guideway-related structural analyses submitted by the Contractor to the Client shall include this vehicle loading.

19.5.2 Other Operations and Maintenance Vehicles

The Contractor shall provide a sufficient number of road-based vehicles to conduct all operations and maintenance tasks, including:

a) Rapid access of O&M personnel to any System location to respond to failure and malfunctions.

b) Assistance in passenger evacuation.

c) Assistance in disabled train recovery.

d) Pick-up and delivery of O&M equipment, parts, consumables, and expendables.

These vehicles shall be suited to and equipped for the purpose intended by the Contractor. All such vehicles shall meet national motor vehicle codes and requirements and shall be locally licensed. All shall have an appropriate color scheme, markings, logos etc. to identify them as System vehicles. They shall have flashing amber lights mounted for visibility by other motorists. All shall have on-board mobile radios, or integral mounts for hand-held portable radios, to give coverage wherever they are driven in the course of their duties and access to the System.

19.6 Maintenance Management Information System (MMIS)

A computer-based Maintenance Management Information System (MMIS) shall be provided with at least the following capabilities:

a) Cost Accounting: Tracking resource expenditures, including labour and materials costs, attributable to each subsystem.
b) Work Order Processing: Recording a comprehensive description of each repair action as well as tracking the status of open and unassigned work orders.
c) Data Retrieval: Retrieve selected and sorted work order data. Retrieve labour and material costs by subsystem.
d) Status Tracking: Documenting subsystems and component assets and repair histories.
e) Serialized Assembly Tracking: Track the maintenance history of all serialized assemblies.
f) Preventive Maintenance (PM) Scheduling: Projecting inspection dates.
g) Failure Monitoring: Documenting component failures for each subsystem.

The Contractor shall provide the hardware, software, and peripherals for the MMIS. All forms, such as work orders, inventory slips, work scheduling sheets, and data input sheets, shall be supplied by the Contractor. All such attributes of the MMIS shall be included as part of the Maintenance Equipment Design package. The Contractor shall use this MMIS during System testing, demonstration, and operations and maintenance.

19.7 Architectural and Engineering (A&E) Requirements

19.7.1 Appearance

The OMSF design shall be compatible in architectural character, materials, finishes, and functional relationships with the rest of the System.

19.7.2 General Characteristics

The OMSF shall have the following characteristics:

- The internal organization shall provide clearly defined zoning of major functions and grouping of complementary functions
- External means of ingress and egress shall be clearly identified by architectural means other than graphics
- Visual and sound screening of maintenance and storage, road vehicle parking, and service delivery and loading functions shall be provided by opaque materials that are compatible with and complementary to the location

- It shall be compatible with the surrounding environment.

19.7.3 Exterior Building Appearance

The bulk and mass of the structures shall be aesthetically assembled.

Generally, changes in materials shall coincide with change in solar orientation, building function and/or fenestration treatments responding to predictable physical impacts on contact surfaces. All exterior finish materials shall be selected to provide resistance to predictable physical impacts including normal usage, weather, vandalism, air pollution, and deterioration due to other forces. Glazing shall be used whenever practicable to reduce the requirements for interior artificial lighting.

19.7.4 Interior Building Appearance

- Ceilings – All ceiling installations shall be designed to facilitate alteration and/or expansion of specific interior functions. Ceilings shall minimize the transmission of disruptive noises from one space to another
- Walls – Walls in maintenance areas shall be constructed and finished to effectively resist predictable impacts and abrasions from the movement and maintenance of vehicles and equipment. Walls near operations involving the use of corrosive agents shall be finished to resist deterioration of surface quality. Walls in administrative areas shall provide for maximum flexibility of spatial arrangement. Walls shall be resistant to sound transmission, compatible with the requirement of moveability
- Floors – Floor areas requiring special finishes shall be identified. Floor surfaces shall be designed to meet the antiskid requirements of OSHA (or alternate government regulations). In the construction and finish of floor surfaces, conditions shall be avoided which represent inherent hazardous conditions, such as arbitrary changes in floor texture without accompanying changes in color.

19.7.5 Vertical Circulation

Enclosed stairwells shall be placed and treated to allow visual surveillance into the stairwell interiors. Exterior stair surfaces shall be protected from the accumulation of water to protect from slippage.

19.7.6 Lighting

Area lighting shall produce the minimum illumination levels shown in Table 19-1, when measured on a horizontal plane 0.76 m above the floor.

Table 19-1 Minimum Illumination Levels in OMSF

Area	Illumination Level (lux)
Shop area	500
Office	750
Stairways and corridors	200

Area	Illumination Level (lux)
Locker rooms and washrooms	300
Inspection and repair benches	700
Storage and parts bins	500

Exterior lighting shall be shielded and directed away from adjacent properties to minimize glare and adverse visual impacts.

19.7.7 Structural

The structural system of the maintenance building shall be designed and constructed for all combined Design Loads, including wind velocities and precipitation as per Section 20.

The structural frame shall provide for maximum flexibility of interior space use. Spacing and placement of vertical supports at the main maintenance level shall provide for the efficient positioning of all maintenance functions and for the ease of movement of vehicles and equipment for maintenance activities.

The structural system shall be protected from fire in accordance with the appropriate provisions and guidelines of local and national standards.

The building shall be suitably insulated for interior comfort and energy conservation.

19.7.8 Electrical

Electrical power shall be provided in all voltages and types needed for all office maintenance and normal housekeeping functions in the OMSF. Power shall include voltages and capacities needed to operate electric motored equipment, battery chargers, welding equipment, HVAC equipment, and all other maintenance equipment.

All electrical equipment, devices, and installations required for the movement, maintenance, and testing of vehicles and other System equipment shall include necessary manual and automatic controls, protective shielding, and automatic power cut-offs to assure personnel safety.

19.7.9 Mechanical Equipment

Mechanical equipment includes all plumbing, heating, ventilating, air conditioning (HVAC), and fire protection systems. All HVAC required for the activities in the OMSF buildings shall be designed and provided by the Contractor. All HVAC and plumbing systems shall be designed for energy efficient operation in accordance with local and national standards. Adequate measures shall be taken to maintain appropriate temperatures and humidity ranges for all employee work areas. Whenever practicable, the systems for maintaining required cooling and ventilation levels shall be augmented using insulation and natural convection.

Areas that shall be considered for air conditioning include offices, computer rooms, and shops for electronic and other sensitive equipment. Special ventilation shall be provided as required by code for shops and storage areas that produce undesirable emissions. All other shop and storage areas shall be adequately ventilated for their functions and given the local climate conditions.

The facility shall be designed to drain waste in areas of frequent wash down, such as vehicle wash areas, vehicle maintenance bays, and toilet and shower areas. The disposal of wastewater shall follow the local effluent standards.

19.7.10 Utilities

Provisions shall be made for installation of and connection to required public utilities.

19.7.11 Handicapped Provisions

The OMSF shall be designed to be accessible.

19.8 OMSF Safety

The OMSF, including the non-revenue guideway and maintenance shops, shall be designed and equipment procured and installed in accordance with the relevant local and national standards.

19.8.1 Overhead Hoist

Hoists and cranes, if applicable, shall meet all local and national standards.

19.8.2 Signage

Warning signs shall be posted in areas containing electrical voltage sources in excess of 120 V and near sources of steam, pneumatic, and hydraulic pressure.

19.8.3 Paint Codes

Work areas shall be color coded to meet local and national standards.

19.9 OMSF Emergency Systems

19.9.1 Fire

An electrically supervised, closed circuit, selective code fire alarm system shall be provided. An automatic sprinkler system shall be provided. Manual fire alarm stations that are readily identifiable and easily assessable to all personnel shall be provided. Automatic devices, such as fixed temperature detectors shall be installed as required by fire codes. Audible and visual alarms and indications shall be provided at local points as necessary.

There shall be automatic shutdown of HVAC systems in the area of an alarm. Instructions for the closing of fire doors, emergency evacuation, and similar functions shall meet relevant local and national standards. Fire extinguishers shall be provided as recommended by local and national standards and the local fire department.

19.9.2 Emergency Power

Emergency and backup power shall be provided.

20 Structural Criteria for Facilities

20.1 Scope and General Requirements

The design of the guideway, stations, maintenance and storage facilities, power substations, and other System support structures shall incorporate all operating and service functions related to the specific technology and meet or exceed the design criteria cited in this section, and the Design Life as specified in Section 3.8. Engineering features include the effects of guideway-vehicle interaction, creep and shrinkage, fatigue, soil-structure interaction, and construction factors.

20.1.1 Design Factors

The guideway superstructure requires special attention to design factors. Suitable forms, guideway appearances, and surface treatments are to be used to enhance the visual appearance.

20.1.2 Traffic Control Lights and Street Lights

The guideway shall be designed and located so as to minimize the interference with both traffic control lights and streetlights.

20.2 Foundations

All foundation settlement amounts, loads, and construction methods shall be determined by the Contractor. An appropriate factor of safety shall be used for all foundations. The foundation shall depend on local soil conditions and can be classified into three types:

- Pile Footings – Piles may be driven, set in predrilled holes, or cast in place. The load capacity and settlement – of individual piles or groups of piles shall be estimated
- Drilled Shafts – Drilled shafts or caissons shall be designed as end bearing, skin friction, or both
- Spread Footings – Spread footing foundations shall be installed dry and shall be founded on a stratum demonstrated to be of sufficient strength and thickness through geotechnical investigations.

The top of foundation spread footing, pile caps, or slabs for drilled caissons shall be at least 30 cm (one foot) from the top of ground to permit landscaping and future utility installations.

20.3 Guideway Structures

The guideway structures shall be designed to support, guide, switch and restrain the monorail vehicles. Guidance of monorail trains includes the ability to switch trains between guideways per Section 17.4. The guideway shall also perform all other required tasks such as providing emergency access and egress capability, maintenance and operations access, safe refuge (walkways), support of wayside power distribution services, and housing of automatic train control equipment.

Elevated guideway superstructures shall be precast concrete, cast-in-place concrete, structural steel, or combinations of these forms of fabrication. These guideway components may be constructed in place or prefabricated and transported to the site.

The allowable superelevation of guideway curves and minimum radius for passenger service shall be in accordance with vehicle supplier. At higher radii the superelevation shall be reduced to maintain a comfort speed of 80 km/h and above if train is capable of such speeds.

The design of curves for passenger service, the allowable cant deficiency, and the vehicle speed through curves shall be governed by the maximum Sustained Transverse acceleration and Jerk values imparted to a vehicle by the geometry of the guideway, as are given in Table 20-1. Vehicle speeds through curves shall also be adjusted as necessary to meet ride quality, jerk, and reliability requirements. “Sustained”, “Lateral”, and “Vertical” shall be as defined in Section 2.1. Lateral and Vertical acceleration values shall be obtained with a standard piezoelectric accelerometer with a frequency range of at least 0.1 – 80 Hz.

Design of curves in areas that do not have passenger service shall be governed by safety, reliability, and availability.

Table 20-1 Maximum Acceleration Values Imparted by the Guideway in Passenger Service

	Design Radius	Sustained Transverse Acceleration	Jerk
Lateral	R > 90	0.05 g, 0.5 m/s^2	0.06 g/s, 0.6 m/s^3
	60 ≤ R ≤ 90	0.03 g, 0.3 m/s^2	
	R ≤ 60	0.0 g, 0.0 m/s^2	
Vertical		0.05 g, 0.05 m/s^2*	0.04 g/s, 0.4 m/s^3

* With respect to a 1 g datum, 9.80665 m/s^2

Vibration of the guideway during the passage of a transit vehicle induces vehicle motion that can be detrimental to passenger comfort. The guideway shall be designed to provide an acceptable level of passenger comfort by consideration of the vehicle-guideway interaction. The guideway can also be influenced by adjacent highway loads. The design shall isolate the guideway from these conditions.

Continuous beams have frequencies of higher flexural modes that are closer to the fundamental frequency than is the case for simply supported beams. Consequently, care shall be taken to ensure that these higher frequencies for a continuous beam do not coincide with a relevant frequency of the monorail vehicle. Attention shall also be given to the torsional frequencies of the guideway and the vehicle on the guideway.

Deformation in members under sustained loading shall be calculated as the sum of the immediate deformation and the long-term additional deformation. Deflections, which occur immediately upon application of load, shall be computed by the usual methods for elastic deflections.

All the torsion design provisions currently available deal with members of bulky, cross section. For such members, St. Venant torsion predominates, and the warping torsional resistance can be ignored without appreciable error. However, thin-wall and open sections, when used as guideway members, shall be investigated for warping torsional resistance.

20.3.1 Running and Guidance Surfaces

The Contractor shall provide the final vehicle-running surface as part of the guideway structure. The Contractor shall establish alignment, design, construction criteria and construction tolerances for the running surface and its installation. The Contractor shall verify the accuracy of the constructed surface to assure that the ride quality, noise, vibration, alignment, and guideway structural requirements of this are met.

Deflections and rotations attributable to loading, including pre-stress and volume changes due to temperature, creep, and shrinkage, shall be considered in the design since these can affect the structure and ride quality. Of particular importance is the angular discontinuity between the top surfaces at the ends of beams at a joint.

If the running surface is painted or otherwise coated (e.g., in switches), the coating shall ensure that adequate traction is provided for safe stopping distances and normal acceleration/deceleration. The coating should colour-match adjacent paint or coating. The running surface coating application shall ensure durability such that it and its tractive ingredients shall not spall or otherwise separate from the guideway for at least five (5) years and be readily restored.

20.3.2 Design Loading Factors for Running and Guidance Surfaces

The Contractor shall design the running and guidance surfaces and structures for the Design Load conditions and other requirements of the System. In addition, the load conditions for the running and guidance surfaces shall be designed to avoid surface deterioration from contact stresses, vehicle dynamics and fatigue problems. All maintenance procedures, required to maintain the minimum running and guidance surface conditions consistent with the structural design and ride comfort criteria, shall be identified by the Contractor and included in the Maintenance Plan of the System.

20.4 Station Structures

Station structures shall be constructed of durable materials and designed in accordance with applicable local and national building codes. Station structures shall have a minimum of 50-year life cycle without major repair or replacement or that specified by the Owner. The station platforms must be suitably connected to the guideway to avoid excessive gap variation for passengers.

20.5 Design Specifications and Applicable Codes

The design of structures constructed as part of the System shall meet local and national codes as required by law.

20.6 Landscaping

In general, landscaping affected by the construction of the System shall be restored to its original state (that prior to the construction activity). Treatments around permanently modified areas shall be to the level of finish of the original landscaping.

21 Construction Criteria

21.1 Scope and General Requirements

During handling and installation of work at the project site, the Contractor shall protect adjoining work and work in progress based on continuous daily maintenance. The Contractor shall clean, maintain, and apply protective coverings as necessary on installed work to ensure freedom from damage or deterioration during the construction period. The Contractor shall maintain a clean, organised, and safe site at least to the local standards and Section 7.3.

The Contractor shall restore any infrastructure, streets, roads, facilities, and utilities (including landscaping) disturbed during construction or System installation. This includes removing all debris and cleaning the site.

Construction will include elevated, at-grade, and subsurface facilities as required. The Contractor shall be responsible for the following:

- Permits and licences required for construction
- Contractor laydown areas, staging areas, construction easements (Client responsibility), offices, and services
- Maintenance of adjacent property access
- Maintenance of emergency access egress, and bypass
- Archeological, historic, and park preservation regulations
- Maintenance of pedestrian and vehicular traffic
- Maintenance of traffic control and control devices
- Maintenance of all public and private utilities
- Restricted working hours and weather delays
- Construction safety and life-safety procedures
- Adjacent property condition surveys, underpinning, and instrumentation
- Temporary drainage and erosion control
- Air, noise, vibration, and water pollution control
- Protection in place, temporary and permanent relocations of existing utilities for construction purposes.

22 Corrosion Control and Grounding

22.1 General

The Contractor shall provide corrosion control measures against damage to, or premature failures of, structures or System equipment or nearby underground utilities due to corrosion. These corrosion control measures shall be designed and selected in accordance with EN 50122 Part 2.

The Contractor shall provide grounding systems that will control the risk to passengers and operations and maintenance personnel from hazardous voltages and currents, whether due to normal System power, other adjacent power sources, electrical faults, or lightning, according to EN 50 1153. The grounding systems shall also control against equipment damage resulting from such sources according to EN 50122 Part 1.

The following issues shall be addressed by the Contractor's System design:

- Soil and Water Corrosion Prevention: System structures shall be protected from soil and water corrosion by the appropriate choice of materials, coatings, insulation, electrical continuity, or cathodic protection as appropriate
- Stray Current Corrosion Prevention: Unless appropriate mitigation measures are taken, stray currents from DC propulsion systems can cause rapid deterioration of buried metallic structures. The Contractor's design shall minimize the flow of stray currents
- Atmospheric Corrosion Prevention: System equipment and structures shall be protected from atmospheric corrosion through the appropriate choice of materials and coatings
- Grounding: The design of grounding systems for propulsion power substations, passenger stations, elevated structures, the OMSF, and other System components shall not compromise corrosion control measures and shall minimize electrical hazards. Refer to Section 22.4.

22.1.1 Interfaces

The Contractor shall coordinate corrosion control and grounding with all utilities, and with the mechanical, civil, structural, electrical, propulsion power, environmental, geotechnical, architectural, and other subsystems. Corrosion control and grounding shall be coordinated throughout the design, installation, and start-up processes of the System.

Corrosion control, substation and System grounding designs, bonding design, and lightning protection requirements shall be coordinated, and their designs shall be compatible with relevant safety requirements.

22.1.2 Provision for System Expansion

The corrosion control and grounding designs shall be applicable to the entire System without major reconfiguration, reconstruction, or duplication of equipment. The effects of possible future extensions and expansions of the System, as contemplated in Section 3.6 shall be considered and provided for in the design of the corrosion control and grounding systems.

22.2 Stray Current Corrosion Prevention

Transit systems that use direct current traction power distribution systems, especially with poorly insulated return rails tend to produce stray currents in the guideway structures and/or in the ground. These stray currents can cause corrosion of guideway structures or adjacent structures or buried utilities. Structures and systems that could be affected by stray currents include components of the power system, reinforced concrete structures, steel structures, metallic pipes, casings, and other buried metallic structures.

The Contractor shall perform calculations to predict the magnitude of anticipated stray currents for the System and shall take measures to avoid such stray current corrosion.

22.2.1 Stray Current Corrosion Prevention Measures

In order to avoid stray current corrosion from occurring, the Contractor shall:

- Design the power distribution system to minimize the level of stray currents
- Incorporate design features to control the path of any residual stray currents.

22.2.2 Minimization of Stray Currents

The most effective means to limit stray current corrosion is to minimize the magnitude of stray current, and therefore the Contractor's design shall be directed toward this end. The design shall incorporate the following features:

- The system for distributing power to the vehicles, consisting primarily of the power-rail system, shall be insulated from the guideway structure. The resistance to earth of each conductor bar system (each positive and each return rail) shall be a minimum of 300 kΩ/km dry, and shall be a minimum of 30 kΩ/km for an individual rail when wet, measured at an applied voltage of 1,000 V. This resistance shall be maintainable during the life of the System
- The conductor rail system shall be operated as an electrically continuous bus with no breaks, except during emergency or fault conditions.

22.2.3 Residual Stray Current

If the level of conductor-rail-to-earth isolation specified in Section 22.2.2 cannot be achieved, the Contractor shall investigate additional measures to control stray current. These may include any of the following:

- Electrical bonding of steel structures and reinforcing bars throughout the System to make them electrically continuous
- Installation of stray current drainage cables to electrically connect such structures and reinforcing bar to the substation negative busses
- Installation of stray current drainage cables to electrically connect any buried metallic pipes that cross the System, or that run parallel and close to the Right-of-Way, to the substation negative busses
- Provision of stray current drainage facilities in traction substations, including insulated negative drainage busses, cables, cable terminations, diodes, and shunts or equivalent means to measure the drainage current.

22.2.4 Stray Current Monitoring Systems

For systems that use direct current traction power distribution, substations shall include provisions for stray current monitoring.

If the level of conductor-rail-to-earth isolation specified in Section 22.2.2 is not achieved, the Contractor shall investigate stray current monitoring systems throughout the System. These may include any of the following:

- Analog inputs to the SCADA system, to allow the monitoring of the levels of stray current at each substation negative return bus from the control center
- Test terminals at each guideway column and each guideway beam to allow measuring the voltage between the reinforcing bar in the column or beam and ground
- Test terminals for all buried metallic utility pipes or structures that cross the system, or that run parallel and close to the Right-of-Way, to allow measuring the voltage between the pipe or structure and ground.

22.3 Atmospheric Corrosion Prevention

To reduce maintenance costs and preserve the appearance of facilities and fixed equipment provided for the System, the following criteria shall be met:

- Materials Selection – Materials selected for use on the System shall have established performance records for the service application
- Sealants – Sealants shall be used in crevices to avoid the accumulation of moisture
- Protective Coatings – Barrier or sacrificial coatings shall be used on exposed steel surfaces
- Design – The use of dissimilar metals and recesses that trap moisture shall be avoided.

22.4 Grounding

The Contractor shall provide a grounding system for System equipment (including, but not limited to power distribution system equipment). The grounding system shall be designed, constructed and installed in accordance with good engineering practice and with applicable codes and standards.

The grounding system shall:

- Protect persons using or maintaining the System from unsafe touch voltages or potential gradients at all times, and in particular during electrical faults
- Provide a low impedance ground path for lightning surges
- Provide protection to electrical equipment by limiting the voltage stress to which equipment is exposed during fault conditions
- Be designed in accordance with the stray current corrosion control plan (refer to Section 22.2 to minimize the damage that might otherwise be caused by such stray currents
- Be designed with careful consideration of electromagnetic interference (EMI) and electromagnetic compatibility (EMC) considerations.

Wayside grounding design shall provide low resistance meeting local requirements. As an example, a continuous ground conductor shall be provided along the entire length of the guideway. Any exposed metallic structures along the guideway shall be connected to this ground conductor. This ground conductor shall be connected to properly designed and constructed ground electrodes at regular intervals. Such ground electrodes shall be provided at electrical substations, passenger stations, and at guideway structure foundations.

Ground electrodes for outdoor electrical substations shall consist of a ground bus connected to ground rods and conductors interconnected to form a low-resistance ground grid. Such grids shall be designed in accordance with local and national standards to ensure that step-and-touch potentials are limited to safe values. All conductors in the ground grids shall be rated to withstand the anticipated range of short-circuit currents without damage.

Within electrical rooms, ground plates shall be provided at several locations on or near the perimeter wall connected directly to the ground grid. The substation ground bus shall be connected directly to these plates. A dedicated insulated ground bus shall be provided, where necessary, for electronic equipment grounds.

The Contractor shall coordinate the designs of the corrosion control systems and the grounding systems to ensure that they are compatible in all respects and that there is no conflict between them. The general propulsion power grounding requirements are listed in Section 9.8.7; more specific requirements are listed Sections 22.4.1, 22.4.222.4.3 below.

22.4.1 Automatic Grounding Switches

The grounding system design shall minimize the risk that passengers and System maintenance personnel are not exposed to unsafe voltages at any time and in particular during fault conditions. Such unsafe voltages could occur in an ungrounded DC distribution system if one pole (e.g., the negative) was connected to the vehicle structure and the other pole (the positive) faulted to ground.

If the conductor rails in the Contractor's propulsion power distribution system are normally ungrounded, and if there is no separate non-current-carrying ground rail for the vehicles, then each passenger station or substation shall be equipped with an over-voltage limiting device (OVLD). The device shall ground the negative return system if unsafe voltages occur between the negative conductor rail and ground. The switch may be electromechanical or electronic, but in either case it shall be capable of closing in 50 ms or less.

The operation of the automatic negative grounding switch shall be initiated by an overvoltage detection device connected between the substation negative bus and ground. The overvoltage detection device may have an adjustable voltage threshold and shall incorporate means to avoid false triggering on voltage transients.

The automatic negative grounding switch may be equipped with an instantaneous overcurrent relay and a timer. If circuit breakers do not clear the fault within a pre-set time, the timer shall initiate tripping of all feeder breakers

22.4.2 Passenger Stations and Facilities

Ground electrodes for passenger stations and the OMSF shall consist of a buried-grid-and-rod system. Interconnection with steel pilings or reinforcement shall be provided as necessary to reduce touch potentials. Grounded equipment, metal enclosures, motors and similar equipment shall be located to preclude contact by passengers wherever possible.

Interconnections shall not be made between ground mats and water pipes or other underground utility structures.

The Contractor shall coordinate the design and material selections for the vehicles, passenger station platforms, grounding systems, and corrosion control systems to ensure that all safety, corrosion control, and other requirements stated are satisfied.

22.4.3 Elevated Structures

Metal structures located on the elevated guideway that may be contacted by passengers or maintenance personnel, such as handrails and cable tray components, shall be made electrically continuous and connected to ground. The connection to ground shall be made in such a way that stray current corrosion control requirements are not compromised.

23 Quality Assurance / Quality Control

23.1 Requirements

This section describes the requirements for preparation of the Contractor's Quality Assurance/ Quality Control (QA/QC) Program that shall be implemented and maintained by the Contractor.

The QA/QC Program shall comply with the requirements of the International Standards Organization (ISO) 9000 Series Standards and define an effective quality management process as per EN 50126.

When the Contractor has an established quality program that meets the intent of the ISO 9000 guidelines, it will not be required to develop a new QA/QC Plan but shall be required to adopt or modify its current program in areas such as organization, responsibilities, processes, schedules, etc. to meet the particular requirements for this project, or to state how those pertinent areas will apply within the established quality structure.

23.2 Quality Assurance and Quality Control Program Plan

23.2.1 Purpose

The Contractor shall maintain a comprehensive QA/QC plan to regulate methods, procedures, and processes to assure compliance with the Contract requirements, including design quality and software quality assurance. The intent of the plan shall be to ensure that the methods, procedures and processes consistently function as expected and produce results that consistently meet the requirements and specifications.

The Contractor shall submit to the Client's Representative its proposed QA/QC Plan per the schedule in Section 26.1.

The Plan shall describe, as a minimum, the organization and personnel to be used to undertake QA/QC activities, the requirements of the program, the method of implementation, use of third-party assessors, methods of detecting and correcting non-conformance, reporting procedures. It shall anticipate the Quality Management Report of Section 23.4.

23.2.2 Procurement Quality Assurance and Control

The Contractor's QA/QC Plan shall outline the methods to be used for the selection and control of suppliers and subcontractors. These methods shall describe:

- Selection of qualified procurement sources
- Evaluation and assessment of the quality programs provided by major suppliers and subcontractors
- Monitoring of the suppliers' and subcontractors' quality performance
- Transmission of all design, reliability and quality requirements to procurement sources
- Evaluation of procured items against purchase order and subcontract requirements
- Provisions for early and effective information feedback and correction of non-conformance.

23.2.3 Software Quality Assurance

Software development undertaken for the Project shall be monitored using the guidelines of ISO 9001 and the procedures for software quality assurance shall be included in the QA/QC plan.

23.2.4 Production Operations

The Contractor shall ensure that all manufacturing functions are accomplished under the Quality Assurance/Quality Control Plan.

23.2.5 Calibration and Certification of Measuring Equipment and Tools.

The QA/QC plan shall describe, and the Contractor shall implement an effective, time-cycled, or usage-cycled calibration and certification program for measuring equipment and tools including:

- Use of inspection, measuring and test equipment of the range necessary to determine conformance
- Calibration against certified standards based on ISO or nationally approved standards.

23.2.6 Handling, Storage and Delivery

The Contractor's QA/QC Plan shall provide inspection instructions for handling, storing, preserving, packaging, marking, and shipping so as to protect the quality of products and to avoid damage, loss, deterioration, degradation, or substitution thereof.

23.2.7 Qualification of Personnel

The QA/QC plan shall describe, and the Contractor shall assure that only properly qualified personnel shall be employed in the execution of the work. The records of inspection and testing personnel certifications shall be maintained and monitored by the QA/QC personnel. Such records shall be available for audit by the Client's Representative at all reasonable times.

23.2.8 Quality Records

The QA/QC plan shall describe the records that shall be maintained by the Contractor to demonstrate the effective operation of the Quality Assurance/Quality Control Plan. The records shall contain objective evidence as to whether quality goals have been attained. Such records shall be available for audit by the Client's Representative at all reasonable times.

23.2.9 Scope of Quality Records

The Quality records shall include the results of inspections, tests, process controls, certification of processes and personnel, deficient material (including records of disposition), and other quality requirements defined in the Contract.

23.2.10 QA/QC Control System

The QA/QC plan shall describe, and the Contractor shall implement and maintain QA/QC Control Systems throughout the life of the Contract including:

- A system for identifying the inspection status of material parts components or assemblies at any level as to their acceptance, rejection, or non-inspection
- An effective and positive system for controlling nonconforming material, including procedures for identifying, segregating and designating non-conforming material for repair, rework or other disposition.

23.2.11 Client's Representative Rights

The Client's Representative shall have the right to verify, by audit, elements of the Contractor's Quality Assurance/Quality Control Plan at all times, as it is deemed necessary.

The Client's Representative reserves the right to inspect at the source any items furnished, or services rendered. The Client's Representative's inspection of a supplier's or subcontractor's facility will be coordinated with the Contractor.

The Client's Representative's inspection at a supplier's or subcontractor's facility shall not constitute evidence of effective quality control by such supplier or subcontractor.

23.2.12 QA/QC Inspections

The following inspection requirements are to be part of the QA/QC Plan. All inspections shall be performed by qualified QA/QC personnel as appropriate to the inspection.

23.2.12.1 Inspection Plan (IP)

The Contractor shall submit to the Client's Representative for review a detailed Inspection Plan (IP) covering all project-related activities at locations other than at the Site per the schedule in Section 26. The Contractor shall also submit to the Client's Representative for review a detailed Inspection Plan covering all work at the site per the schedule in Section 26.

The Inspection Plans shall be used for the inspection of the works and shall be revised and resubmitted for the Client Representative's information, if the Contractor desires to change the sequence, method or nature of the inspections or if the sequence, method or nature of the inspection and testing is not in accordance with the current approved Project Schedule. The Client Representative's reviews/comments of the Inspection Plan shall not relieve the Contractor of its responsibility for the inspection and performance of the works as provided for in this Contract.

The Inspection Plans shall include a detailed description of each item or part of the works to be inspected, the nature and frequency of the inspection, and the type and size of the samples to be taken, if any, the means of recording the inspection data, the name and specific responsibility of any proposed inspection agency or sub-consultant, and all other information necessary or required to describe the inspection to be performed for the Works. Inspection, in and of itself, indicates that a specific item complies with the Contract requirement or requires further action, the inspection shall not be considered to guarantee quality, especially with respect to safety-critical components.

The Inspection Plans shall identify who, what, when, and where in the processes of design, production, assembly, shipment, installation, commissioning, and acceptance that all inspections will be performed. They shall also include a hold point reference that identifies specific points during design, production, assembly, installation, etc., where work shall not proceed without the Contractor's QA verification of acceptability. Copies of the Contractor's manufacturing plans, manufacturing flow diagrams, etc., shall be submitted with the IP for work to be performed off-site.

23.2.12.2 General Inspection Requirements

The Contractor shall progressively inspect all items of the Works as described in the approved Inspection Plans and required by the Contract. Adequate reports of all inspection activities shall be maintained by the Contractor and the reports shall be made available for the Client’s Representative's review upon request.

Inspection shall occur at appropriate points in the manufacturing and installation sequence as necessary to ensure procedures are maintaining compliance with drawings, specifications, process specifications, and quality standards. These inspection measures shall be used to preclude the use of incorrect or deficient materials or components and to assure that only correct and accepted items are used and installed.

Inspection shall allow identification of any item of production (batch, lot, part) at any stage, from initial receipt through fabrication, installation, repair, or modification to an applicable drawing, specification, or other pertinent technical document. Permanent physical identification shall be used to the maximum extent possible.

Inspection procedures shall provide for reporting to designers any unusual difficulties, deficiencies, or questionable conditions, and requiring their disposition on all repair, or use-as-is non-conformances.

Nonconforming material or material designated "Repair" or "Use-as-is" shall not be used for the Work without the QA’s approval of Deviation or Waiver Request on significant or safety critical items.

When modifications, repairs, or replacements are required, they shall be re-inspected for characteristics affected.

23.2.12.3 Receiving Inspection

The Contractor shall provide for the inspection of all incoming materials upon receipt as necessary to maintain quality targets as identified in the QA / QC plan. Inspection may be by statistical sampling, if appropriate.

23.2.12.4 Statistical Sampling Plans

Statistical sampling used for inspections and testing shall be identified in the Quality Assurance/Quality Control Plan, documented in the respective Test and Inspection Plans, and based on generally recognized and accepted statistical quality assurance practices. Sampling plans may be used when tests are destructive or when quality trend data or inherent characteristics of the product indicate that a sampling system of testing or inspection can be used without jeopardizing quality.

23.2.12.5 Physical Examination, Measurement and Tests

Physical examination, measurement, or tests of the material or products processed shall be required for each work operation as necessary to maintain quality targets as identified in the QA / QC plan and shall be accomplished in a suitable systematic manner selected by the Contractor. This shall include:

- Adherence to the selected methods for inspection and monitoring
- Corrective action taken when non-compliance occurs
- Criteria for verification and rejection.

Only products that conform to the quality targets shall be provided by the Contractor.

23.2.13 Release for Shipment Inspection

The Contractor shall perform final inspections prior to shipment as required to assure that all the equipment provided complies with the requirements and shall be detailed in the QA / QC Plan.

The Contractor shall submit inspection results to the Client's Representative, if requested. This shall include a list of all non-conformances and their disposition for all materials, components, sub-assemblies, and the final assembly.

23.2.13.1 Installation Inspection

The Contractor shall inspect installations as necessary to maintain quality targets as identified in the QA / QC plan.

Once installation activities have started for major assemblies, summary reports shall be generated and submitted to the Client's Representative monthly or as completed verifying the conformance to the requirements and acceptability of all elements of the work.

These reports shall include the following:

- Outline of activities and actions of the QA/QC engineer as indicated in the QA / QC Plan
- Summary of inspection activities and inspection results
- Outline of conditions adverse to quality and the corrective actions implemented.

The Contractor shall submit any or all inspection results to the Client's Representative, if requested. This shall include a list of all non-conformances and their disposition.

23.3 Compliance

The Contractor shall be responsible for the implementation and maintenance of the approved QA/QC Plan.

The Contractor's QA/OC Plan shall establish and maintain independent evidence of compliance with all of the requirements of the Contract and the Contractor's internal design control standards including verification and validation.

23.3.1 QA/QC Audits

The Contractor's QA/QC Plan shall include a comprehensive system of periodic audits (including comprehensive quality system audits) in accordance with ISO 9001 to be carried out by the Contractor to verify compliance with all policies and procedures that affect quality and determine their effectiveness. Audits shall be performed at predetermined intervals and by qualified personnel not having direct responsibilities in the areas audited.

Audits shall be performed of the Contractor's work and of work performed by major suppliers and subcontractors consistent with activities being performed.

23.3.2 Certificates of Compliance

Certificates of Compliance for certain equipment or materials and products will be accepted by the Client's Representative in lieu of the specified sampling and testing procedures, as described in the QA/QC plan.

23.3.3 Corrective Action Procedures

As part of the QA/QC Plan, the Contractor shall establish, maintain, and document procedures to assure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations and defects in design, material, workmanship, and equipment shall be promptly identified and corrected in accordance with ISO 9001. The corrective action plans shall be made available to the Client's Representative. The procedures shall be submitted to the Client's Representative upon request. The procedures shall include the following:

- Identify conditions adverse to quality, determination of the cause, and corrective action to preclude repetition of such conditions
- Corrective actions taken shall be documented and reported to appropriate levels of Contractor's management.

23.4 Quality Management Report

As evidence of an effective Quality Management system the Contractor shall prepare and submit a Quality Management Report according to the schedule in Section 26.3. Quality aspects which shall be controlled by the Quality Management system and included in the Quality Management Report include:

- Oganisational structure
- Quality planning and procedures
- Specification of requirements
- Design control
- Design verification and reviews
- Application engineering
- Procurement and manufacture
- Product identification and traceability
- Handling and storage
- Inspection and testing
- Non-conformance and corrective action
- Packaging and delivery

- Installation and commissioning
- Operation and maintenance
- Quality monitoring and feedback
- Documentation and records
- Configuration management/change control
- Personnel competency and training
- Quality audits and follow-up
- Decommissioning and disposal.

24 Verification and Testing

The verification process shall demonstrate in an orderly, clear, and well-documented manner that the System meets the requirements both as given in this System Performance Specification and as defined by the requirement allocation process described in Section 4.1.1.

To manage the System verification process, the Contractor shall provide a System **Verification, Test, and Acceptance Plan** following the standard methodology for system engineering design, realization, and verification indicated in Section 4, systems engineering. The Contractor shall prepare a compliance verification matrix as part of the **Verification, Test, and Acceptance Plan** in order to provide, for each requirement/criterion, a summary of the requirement/criterion, the method of verification, verification status, reference documents, and any proposed tests for the System, subsystems, and components being provided. This shall include the timeframe, the responsible entity, and other related information. This matrix shall be a report from the requirements management database.

Test procedures shall be submitted prior to testing, upon request.

The Contractor shall provide a final Verification, Test and Acceptance Report, which shall include the compliance verification matrix showing compliance to the requirements and providing an index to all of the documents that demonstrate compliance. The documents proving the compliance shall be included in the report as well, including test procedures and test reports. All documents shall be submitted according to the schedule in Section 26.

24.1 Verification Methods

Compliance with the requirements shall be verified by analysis, similarity, certification, inspection, or testing. The selected method shall be determined based on the nature of the requirement as well as the service-proven history and the importance and consequence to System operational performance and safety.

24.1.1 Analysis

For those cases in which the Contractor selects the verification method “Analysis”, it shall provide documentation of modeling, simulation, or engineering calculations that demonstrate that the System or subsystem elements meet the design and performance requirements.

24.1.2 Similarity

For those cases in which the Contractor selects the verification method “Similarity”, it shall provide supporting test data from a previous application which demonstrates that the System, subsystem, or component met the same design and performance requirements.

24.1.3 Certification

For those cases in which the Contractor selects the verification method “Certification”, it shall provide evidence of appropriate certification of compliance by a reputable agency. Commercial products are typically verified by certification by recognized independent testing laboratories.

24.1.4 Inspection

For those cases in which the Contractor selects the verification method “Inspection”, it shall be obvious from direct measurements or observation of physical properties that these observations or measurements demonstrate compliance with the design and performance requirements. For example, items for which compliance is demonstrated by formal review of detailed engineering drawings and specifications fall into this category.

24.1.5 Test

Compliance with requirements shall be demonstrated by testing in any case where verification is not shown to the Client’s satisfaction by any of the other methods listed above. In these cases, the Contractor or vendor shall perform tests that clearly demonstrate that the System, subsystem or component meets the performance requirements, the operational requirements, the safety requirements, and satisfies all requirements applicable to final acceptance as outlined in Systems Engineering. In any event, the overall System shall be validated by testing to show appropriateness to the application. It is clear that compliance to many requirements can only be verified by testing and hence tests are required. These tests can generally be categorized as described in Section 24.2 below.

24.2 Test Program

The Contractor shall submit a **Preliminary and a Final Inspection and Test Plan** in accordance with the Data Submittal Schedule in Section 26, setting out the work to be undertaken to meet the requirements of the Verification, Test, and Acceptance Plan, identifying the tests or groups of tests to be undertaken. The Inspection and Test Plan shall provide for the testing of systems, subsystems, equipment and materials as required, and the documentation of tests to ensure verification of requirements including providing a safe and operable transit System. As part of the Project Schedule submittal the Contractor shall develop a comprehensive program for the execution of the Inspection and Test Plan.

The Contractor shall propose templates for documentation of testing. This documentation shall consist of the following elements:

- Test Procedures covering each testing activity on a step-by-step basis
- Test Reports for the recording of the detailed results of the testing process and calibration of test equipment
- Test Certificates that shall report the status of the completed test or group of tests for which the approval of the Client’s Representation is sought.

All test documentation shall be subject to audit by the Contractor's QA/QC department and certified as complying with the approved QA/QC Plan before submission to the Client in accordance with the Data Submittal Schedule in Section 26.

Test procedures shall identify the parameters that will be measured and recorded and will establish the pass/fail criteria. The test procedures shall also define the instrumentation that will be used for the tests. Where quantitative data is required as part of the verification process, instrumentation, sensors and recorders shall be installed and calibrated to applicable standards. All instrumentation shall be identified in the appropriate test procedures and have proof of current calibration.

Test Reports and Test Certificates shall show unambiguously the extent of testing covered by each such Certificate or Report, the relevant drawings (or modification) status, the testing location, the name and signature of the person responsible for each test, the date of testing, and the calibration status of all test equipment. The test results shall also include numerical values where applicable for such items as power supply conditions, system response times and operating characteristics of specific System elements such as power system protection relays.

The Client, or its appointed agent, may monitor all tests and shall have free access to any facilities where tests are in progress, and to all test records. Time shall be allotted in the testing program so that, if necessary, alterations to equipment, systems and designs can be carried out, and the alterations re-tested prior to final commissioning, to meet the time for completion of the Works.

24.2.1 Test Categories

The tests performed generally fall into the following main categories:

- Type Tests
- Routine Tests
- Factory Acceptance Tests
- Site Acceptance Tests
- Post-installation Check-out Tests
- Subsystem Integration Tests
- System Integration Tests
- Safety Qualification Tests
- The System Demonstration or Trial Running (Validation) Test.

24.2.2 Type Tests

Most subsystems and components will be manufactured and assembled in factories prior to shipment to site or assembly on a vehicle. It is expected that in most cases these subsystems and components will have been thoroughly proven by prior service and testing, hence they will be verified as meeting the requirements of this specification through similarity, certification, or inspection. However, if a subsystem or component is modified or new, in either design or application, then type testing will normally be required to verify compliance to requirements. Typically, subsystems or components verified by similarity will have type testing completed previously so further type testing will not be required, however such type tests will require type test data submission and will be subject to the data submittal schedule. Typically, subsystems or components verified by certification, or inspection will not require type test data submission.

Vehicles can also undergo type testing to homologate a series.

The Contractor will propose the type tests required for each such subsystem or component as part of the Inspection and Test Plan. The type tests shall be sufficient to prove compliance to requirements, generally as specified by local or international norms and standards.

The following are examples of typical type tests:

- Vibration and impact resistance
- Mechanical strength
- Environmental (temperature, humidity and water) resistance

- Fire testing
- Performance and timing
- Accelerated life tests
- Electromagnetic compatibility tests
- Electrical and electronic testing.

24.2.3 Routine Tests

Routine tests, also known as production verification tests, are tests performed at the factory on each manufactured component and subsystem to verify key parameters that cannot be ensured by the consistency of the manufacturing process. These tests are generally performed within the production process.

The routine tests performed for each subsystem or component shall be identified by the Contractor in the Inspection and Test Plan, excepting those subsystems and components verified by certification or inspection. The test procedures shall be submitted as part of the Verification and Test Report; however, results of these tests will not be submitted except upon request. The Contractor shall have available the records of the results of these tests for all production.

The routine tests shall be sufficient to maintain compliance to requirements of the subsystem or component despite variations in quality from the production process.

Typical production testing may include the following (as appropriate):

- Physical inspection
- Dimension check
- Functional check
- Electrical check
- Calibration
- Output check
- Operational test
- Load test
- Flashover test
- Insulation test
- Soak test
- Software and data check.

Selected materials and components may be subjected to analysis, environmental, and life testing on a sampling basis sufficiently frequently to allow isolation and replacement of suspect materials and components.

Units that are required to have high reliability characteristics, such as signaling safety equipment, shall be subject to a soak or burn-in period as part of the testing required under this article.

Where microprocessor-based or computer-based equipment is being used, factory tests shall be carried out not only on the hardware but also to validate the software and data used in this application.

24.2.4 Factory Acceptance Tests

The Contractor shall conduct tests as appropriate to verify that any factory-produced components and subsystems will meet the requirements as shipped from the factory. These tests shall include a First Article Inspection (FAI) on the first items from production of all factory-produced components and subsystems, except those verified by certification.

A series of post-installation tests shall be completed for the vehicle-mounted equipment as part of the vehicle pre-delivery testing at the vehicle production facility. These tests shall address:

- Wiring check
- Diagnostic functions
- Public Address system functions.

24.2.5 Site Acceptance Tests

The Contractor shall conduct tests as appropriate to verify that components and subsystems will meet the requirements as received from the factory. Such tests are appropriate for commercial, delicate, or items that have the potential to harm people or property should issues have arisen in shipment. Site acceptance tests shall demonstrate that the subsystem is safe to integrate with the System.

24.2.6 Post-installation Check-out Tests (On Site)

Post-installation check-out (PICO) testing shall be performed on site to determine that the equipment and facilities have been installed correctly on site and are in conformance with the Contract. This testing shall progress systematically so that the elements are tested in a sequential and logical manner (consistent with the Project Schedule) from an established starting point to a pre-determined completion point prior to the commencement of testing of subsystems. Test procedures shall reflect the logical sequence of tests to be performed, progressing from component tests to subsystem functional tests.

The Contractor shall verify that for each installation:

- Measuring and test equipment used in field installation or testing shall be certified to be in calibration at the time of use
- Proper methods of cabling, terminating, grounding and identification have been utilized;
- Interfaces are correct
- Positioning and orientation of equipment and hardware are in agreement with the approved drawings
- Completeness and workmanship meet contractual workmanship standards
- Adequate information to identify location, type of equipment, contract number and name, date and name of Contractor's inspector, designated place where items can be checked for acceptance or rejection, and discrepancy sheet to list noted deficiencies and corrective action taken have been provided.

Wherever possible, persons engaged in testing shall not have been engaged in the design or installation of the same equipment.

24.2.7 Subsystem Integration Tests

The Contractor shall organize, at the manufacturer's facility or on-site, if necessary, tests of the individual subsystems (vehicles, ATC, power supply and distribution, guideway, guideway elements, signaling, communications, SCADA, etc.), in so far as is reasonably possible, to verify that the interaction of the subsystem with the rest of the System and the environment is appropriate, safe, and meets the requirements. These will typically include electromagnetic compatibility requirements.

During the integration testing, system-level interfaces between all subsystems shall be verified.

Typically, it is not practical to verify all requirements in subsystem integration tests. For instance, it is difficult if not impossible to create all environmental and failure conditions. In such cases the Contractor shall ensure the requirements are verified as reasonably possible and shall validate that the subsystem is appropriate for the application.

For the signaling system and other subsystems for which the Contractor determines that producing all conditions associated with the subsystem under test is both critical and impractical, it shall require simulation techniques in the Verification, Test, and Acceptance Plan and/or the Inspection and Test Plan to demonstrate subsystem performance under normal, perturbed, and failure conditions, and perform carefully controlled subsystem integration tests on site if appropriate and safe. Any tests by simulation are considered testing and shall be documented and submitted accordingly.

Subsystem integration tests shall be completed prior to the release of the various subsystems to the Site.

The following subsections provide some examples of tests that shall be performed for the individual subsystems. This is not a comprehensive list; it is indicative only of the types of testing to be performed. The Contractor’s Inspection and Test Plan shall provide the complete list.

24.2.7.1 Guideway Elements

Guideway elements include the guideway switches, conductor rail, and miscellaneous hardware. If this equipment is comprised of service-proven equipment that is currently in operation in similar applications, then verification shall be restricted to installation inspection, integration tests, and system performance verification tests described herein.

If the Contractor proposes to supply guideway elements such as guideway switches that are new designs, these shall be subjected to thorough design verification tests. The Contractor’s Inspection and Test Plan shall define these tests.

24.2.7.2 Vehicle Dynamic Functional Tests

Each production train shall be subjected to dynamic functional tests. The Contractor’s Inspection and Test Plan shall define these tests, and they shall be performed in accordance with test procedures prepared by the train builder.

The dynamic tests for each production vehicle shall include a limited set of tests in automatic mode.

24.2.7.3 Automatic Train Control

The manufacture and installation of the Automatic Train Control system shall be accompanied by a comprehensive and thorough set of structured tests. Step-by-step test procedures shall be prepared for each test, and the tests shall be documented. Any deviations from the expected reactions shall be investigated and resolved.

Each element of the ATC equipment shall be tested at each stage of the manufacture and installation cycles. Similarly, in the case of software, each software module shall be tested on a stand-alone basis, and at each subsequent stage of the integration process.

Extensive testing shall be performed at early stages in the production cycles to reduce the risk of problems during the critical field commissioning process.

The ATC subsystem integration test shall be directed at the integration of the hardware and software. The tests shall cover the range of functionality. Of particular importance will be checking the software mapping of the guideway against the physical installation, and validation of all safety features. The series of tests shall be structured on a hierarchical basis, ranging from movements of a single train to fleet operation.

24.2.7.4 Communications Equipment Integration Tests

After installation and PICO testing to ensure correct installation and connection, a series of integration tests shall be completed to ensure that the equipment is functional to requirements. These tests shall include the public address system, radio coverage, CCTV, and SCADA

24.2.8 System Integration Tests

The Contractor shall also undertake testing to verify that the System meets the requirements and is compatible with other equipment and with the project environment.

System Performance Verification Tests shall be conducted to test the hardware, software, and operational procedures under simulated conditions (no passengers, selected vehicles ballasted) to assure operational compatibility and compliance with operational requirements of all aspects of the System. These tests shall include all normal, abnormal, degraded and emergency conditions and all System configurations planned for operation.

These tests shall include:

- Operation under all normal modes of operation
- Operation with acceptable failure modes of the local electric utility supply and PS&D subsystem
- Operational stability under perturbed conditions, and timetable recovery
- Demonstration of design headway
- Demonstration of safe resumption of operation after power outage
- Train recovery
- Use of de-trainment facilities
- Electomagnetic compatibility.

During the System-wide performance verification testing, combined exercises with emergency services or demonstrations to civil authorities shall be performed as may be deemed necessary. Any such tests and exercises are considered testing and shall be documented and submitted accordingly.

It is not possible to verify all requirements in system integration tests. For instance, all environmental and failure conditions cannot be created. For those conditions for which the Contractor determines that verifying the system performance is both critical and impractical, it shall require simulation techniques in the Verification, Test, and Acceptance Plan and/or the Inspection and Test Plan to demonstrate system performance under normal, perturbed, and failure conditions, and perform carefully controlled subsystem integration tests on site if appropriate and safe. Any tests by simulation are considered testing and shall be documented and submitted accordingly.

In general, the Contractor shall ensure the System requirements are verified to the extent reasonably possible and shall validate that the System is appropriate for the application.

24.2.9 Safety Qualification Tests

Safety Qualification Tests are agreed between the Client and the Contractor, and the Safety Authority if any, to establish a level of confidence that the System will perform safely prior to commencing operations. The extent of the testing shall be commensurate with the degree of novelty and complexity associated with the System as designed by the Contractor.

Because completion of the Safety Qualification Tests is contained within the Safety Case, the safety of the System is not fully assured during the test period. Therefore, appropriate precautions, procedures and monitoring shall be provided, to ensure safety of the railway during the test period. A record shall be established which explains when the System is put into service, with or without passengers, with or without precautions, and what is the authorisation level obtained at each stage (provisional or final Safety Approval).

The safety qualification tests are a subset of verification testing; however, they require Safety Management Process oversight and extra documentation in the Technical Safety Report of Section 7.1.7.

24.2.10 System Demonstration Testing (Trial Running)

The System Demonstration Test (or Trial Running) shall be performed to validate that the total integrated System, including staff, is ready to carry the public. The test, when successfully completed, will provide assurance that the System meets the specified requirements and shall demonstrate required System availability. The test shall consist of full-scale scheduled operation of the System using the operating procedures and the O&M providers’ personnel.

This testing shall be performed by the Contractor with the participation of the Client in accordance with the Contractor's approved testing procedures. All testing shall be performed in strict accordance with the approved procedures. The Contractor shall provide technical support during trial running. If the Safety Case has not been accepted prior to performing the System demonstration tests then the same precautions, procedures and monitoring used during the safety qualification testing shall apply.

24.3 Manpower Requirements for Testing

The Contractor shall provide the necessary test engineers and technicians to perform the on-site Systems Integration tests. These engineers and technicians shall be supported by the Operations and Maintenance staff during the System Integration Verification Phase and the System Demonstration/Trial Running Period, because the System will be running in simulated operations and variations thereof during those periods. A portion of the Operations and Maintenance staff will be required during the System Integration testing, and the entire staff will be required for Trial Running.

These exercises will be an inherent part of the O&M staff training program, and a test of their ability.

24.4 Completion

The Contractor shall provide all documentation as required under the System Verification, Test, and Acceptance Plan before issue of the System Acceptance Certificate. Such documentation shall include as-built drawings, manufacturer's detail drawings where applicable, operations and maintenance manuals, test reports and certificates, the Final Safety Report, and the completed System Verification Test and Acceptance Report, including all certificates, test procedures and reports, and the compliance verification matrix. The Final Safety Report shall be accompanied by a letter issued by the Contractor’s System Assurance Director stating that the information presented within the Final Safety Report confirms that the System has been designed and installed in accordance with applicable safety standards and is ready to carry passengers in revenue service.

25 Operations and Maintenance, Manuals and Training

25.1 Operations and Maintenance Planning

Operations and Maintenance (O&M) planning work shall be performed to be the basis for the detailed O&M plans, O&M manuals, O&M training and finally, the Operation and Maintenance of the System.

The O&M plans shall include:

- System Operations Plans based on the requirements of Section 5, including a service plan (based on Section 5.1), plans for normal operations, failure management and emergency operations (based on Sections 5.2, 5.3 and 5.4)
- A System Maintenance Plan (including requirements for spare parts, special tools and test equipment) based on the requirements of Section 5.5.
- A Management Plan that includes a management structure and plans for staffing and mobilization

25.2 Operations and Maintenance Manuals

The Contractor shall supply detailed O&M manuals including:

- System Operating Procedures Manual
- System Operating Rule Book
- System Maintenance Manual
- Illustrated Parts Catalogue.

Taken together these manuals shall contain all the information required to safely operate, service, inspect, maintain, adjust, troubleshoot, repair, replace and overhaul subsystems and components. They shall contain configuration / integration information and shall be supplemented with equipment manufacturer's standard, commercially available, off the shelf manuals, where applicable.

25.3 Training Program

The Contractor shall develop and supply:

- A Training Program, including training methods and required training materials
- Training materials beyond the O&M manuals, including videos and other presentation materials
- Training for the O&M personnel.

26 System Documentation

Throughout this System Performance Specification, numerous reports, analyses, plans, specifications, and drawings are specified for review by the Client. The term “review” used here and elsewhere throughout this System Performance Specification shall mean that the Client will prepare written comments and transmit them to the Contractor on any matters of question, concern, advice and/or direction, when appropriate. The Contractor shall respond to these comments by advising the Client in writing of further action being taken on the matter or providing further information as appropriate.

26.1 Data Submittal Schedule – Project Plans

The data submittal schedule for project plans and similar documents is shown in Table 26-1, below.

Table 26-1 Data Submittal Schedule -- Project Plans

Title	Reference	Submittal Schedule	Submit to Client for
System Expansion Plan	Section 3.6	120 days after NTP	Approval
System Engineering Plan	Section 4.1	90 days after NTP	Information
Configuration Management Plan	Section 4.1.3	90 days after NTP	Information
Noise Control Plan	Section 6.3	120 days after NTP	Approval
Safety Plan	Section 7.1.4	120 days after NTP	Approval
Reliability, Availability, Maintainability Plan	Section 8.2.2	120 days after NTP	Information
System Security Plan	Section 7.2	120 days after NTP	Approval
Construction Safety Plan	Section 7.3.1	90 days after NTP	Approval
Electromagnetic Compatibility Control Plan	Section 6.2	At PDR	Information
Signage and Graphics Plan (Excluding Advertising)	Section 18.2.5	At FDR	Information

Title	Reference	Submittal Schedule	Submit to Client for
Design Management Plan	Section 4.1.4	60 days after NTP	Approval
System Quality Assurance and Quality Control (QA/QC) Plan	Section 23.2	60 days after NTP	Approval
Verification, Test, and Acceptance Plan	Section 24	120 days after NTP	Approval
Preliminary Inspection Plan	Section 24.2	120 days after NTP	Information
Final Inspection Plan	Section 24.2	120 days prior to acceptance testing	Information
Test Procedures	Section 24.2	14 days prior to test if submission requested	Information
Spare Parts, Special Tools, and Test Equipment	Section 19.4	60 days after the last FDR	Information

26.2 Data Submittal Schedule – Design Documentation

The data submittal schedule for design documentation is shown in Table 26-2 below.

Table 26-2 Data Submittal Schedule – Design Documentation

Title	Reference	Submittal Schedule	Submit to Client for
System Design/Construction Interface Manual	Section 4.4.2	90 days after NTP	Information
System Design Review Package	Section 4.2.1	120 days after NTP	Information
Preliminary Design Review Packages	Section 4.2.2	In accordance with the approved Contract Project Schedule	In accordance with the Design Management Plan
Final Design Review Packages	Section 4.2.3	In accordance with the approved Contract Project Schedule	In accordance with the Design Management Plan

Title	Reference	Submittal Schedule	Submit to Client for
System Performance and Failure Management Analysis (SPFMA)	Section 5.3	Preliminary at PDR; Final at FDR	Information
Hazard Log	Section 7.1.4	Preliminary at PDR; Final with Safety Case	Information
System Operation and Fault Recovery Plan (SOFRP)	Section 5.3	Preliminary at PDR; Final at FDR	Information
Power System Load Flow Analysis	Section 10.3	Preliminary at PDR; Final at FDR	Information
Power System Short Circuit, Protection, Grounding, Harmonic and Power Factor Analyses	Section 10.3	Preliminary at PDR; Final at FDR	Information
As-built drawings	Section 4.3.5	As works are completed	Information/ Records
As-Built drawing Index	Section 4.3.5	One month prior to start of System Trial Run	Information

26.3 Data Submittal Schedule – Quality Assurance and Verification Documentation

The data submittal schedule for Quality Assurance documentation is shown in Table 26-3 below.

Table 26-3 Data Submittal Schedule – Quality Assurance Documentation

Title	Reference	Submittal Schedule	Submit to Client for:
Functional Requirements Specification	Section 4.1.1	Preliminary at FDR; Final with Safety Case	Information
Safety Requirements Specification	Section 7.1.4	Preliminary at FDR; Final with Safety Case	Information
Test Reports	Section 24.2	As Requested, and (as required) as part of the Final Verification, Test, and Acceptance Report	Information

Title	Reference	Submittal Schedule	Submit to Client for:
First Article Inspection Reports	Section 24.2	As requested, and (as required) as part of the Final Verification, Test, and Acceptance Report	Information
System Performance Verification Test Procedures	Section 24.2	14 days prior to test	Information
Availability Demonstration Test Plan	Section 8.2.2	120 days prior to acceptance testing	Information
Availability Demonstration Test Procedure – System Trial Run	Section 24.2.10	6 months prior to System Trial Run	Approval
Availability Demonstration Test Report – System Trial Run	Section 24.2.10	14 days after completion of System Trial Run	Approval
Quality Management Report	Section 23.4	2 months prior to System Trial Run	Approval
Safety Case	Section 7.1.3	Design FDR + 90 days Preliminary 2 months prior to System Trial Run Final 2 weeks prior to System Trial Run	Approval
Final Verification, Test, and Acceptance Report	Section 24	30 days after completion of System Trial Run	Approval

26.4 Operation and Maintenance Documentation

The data submittal schedule for Operations and Maintenance documentation is shown in Table 26-4 below.

Table 26-4 Data Submittal Schedule -- Operations and Maintenance Documents

Title	Reference	Submittal Schedule	Submit to Client for
System Operating Plan	Section 5	120 days prior to start of integration testing	Approval
System Maintenance Plan	Section 5.5.1	120 days prior to start of integration testing	Information
Standard Operating Procedures Manual	Section 3.4	30 days prior to start of integration testing	Information
System Maintenance Manuals - Final	Section 25.2	30 days prior to start of integration testing	Information

27 Appendix 1: International Standards for Straddle-Beam Monorails

Table 27-1 Normative Standards

Normative Standard	Description
EN 10025	Non-alloy structural steels delivery condition
EN 12299	Railway applications - Ride comfort for passengers - Measurement and evaluation
EN 12663-1	Railway Applications - Structural Requirements of Railway Vehicle Bodies
EN 13272	Lighting for rolling stock
EN 13452-1	Mass transit brake systems
EN 13452-2	Mass transit brake systems Part 2: Methods of test
EN 14750	Railway applications – Air conditioning for urban and suburban rolling stock
EN 14752	Door System for Rolling Stock
EN 15085-1 A1	Welding of Railway Vehicles and components part 1 general
EN 15085-2	Welding of Railway Vehicles and components part 2 Quality requirements and certification
EN 15085-3	Welding of Railway Vehicles and components part 3 Design Requirements
EN 15085-4	Welding of Railway Vehicles and components part 4 Production Requirements
EN 15085-5	Welding of Railway Vehicles and components part 5 Inspection testing and documentation
EN 15227 A1	Railway Applications – Crashworthiness Requirements for Railway Vehicle Bodies
EN1990:2002+A1	Basis of structural design
EN 1991	Eurocode 1 — Actions on structures. There are many subcategories for this standard
EN 1992	Eurocode 2 — Design of concrete structures. There are many subcategories for this standard

Normative Standard	Description
EN 1993	Eurocode 3 — Design of steel structures. There are many subcategories for this standard
EN 1994 Eurocode 4	Design of composite steel and concrete structures
EN 1997 Eurocode 7	Geotechnical design
EN 1998 Eurocode 8	Design of structures for earthquake resistance
EN 1999-1-1 A2	Eurocode 9: Design of aluminium structures Part 1-1 General structural rules
EN 1999-1-2	Eurocode 9 Design of aluminium structures Part 1-2 Structural fire design
EN 1999-1-3 A1	Eurocode 9 Design of aluminium structures Part 1-2 Structures susceptible to fatigue
EN 1999-1-4 A1	Eurocode 9 Design of aluminium structures Part 1-4 Cold-formed structural sheeting
EN 1999-1-5	Eurocode 9 Design of aluminium structures Part 1-5 Shell structures
EN 1337	Structural Bearings
EN ISO 9606-1	Qualification testing of welders — Fusion welding Part 1 Steels
EN ISO 9606-2	Qualification testing of welders — Fusion welding Part 2 Aluminium
EN 45545	Fire Safety
EN 50110-1	Operation of electrical installations
EN 50121	Electromagnetic Compatibility – Railway Applications
EN 50122-1	Railway applications – fixed installations, Part 1: Protective provisions relating to electrical safety and earthing
EN 50123-1	Railway applications – Fixed Installations D.C. switchgear General
EN 50123-2	Railway applications – Fixed installations D.C. switchgear DC circuit breakers
EN 50123-3	Railway applications – fixed installations – DC switchgear, Part 3: indoor DC disconnectors and switch disconnectors

Normative Standard	Description
EN 50123-5	Railway applications – fixed installations – DC Switchgear, Part 5: Surge arresters and low voltage limiters for special use in DC systems
EN 50123-6	Railway applications – fixed installations – DC Switchgear, Part 6: DC switchgear assemblies
EN 50123-7	Railway applications – fixed installations – DC Switchgear, Part 7: Measurement, control and protection devices for specific use in DC traction systems.
EN 50124-1	Railway applications – Insulation coordination, Part 1: Basic requirements – Clearances and creepage distances for all electrical and electronic equipment
EN 50124-2	Railway applications – Insulation coordination, Part2: Over-voltages and related protection
EN 50126	Railway applications – The specification and demonstration of Reliability, Availability, Maintainability and Safety (RAMS)
EN 50128	Communications, Signalling, and Processing Systems-software for railway control and protection systems
EN 50129	Railway Application: Safety related Electronic System for Signalling
EN 50153	Protection re electrical hazards
EN 50155	Railway applications - Electronic equipment used on rolling stock
EN 50159	Railway applications Communication, signalling and processing systems Safety-related communication in transmission systems
EN 50207	Railway Applications Electronics Power Converter for Rolling Stock
EN 50327	Converter groups and tests on converter groups
EN 50328	Railway applications – fixed installations, Electronic power converters for substations
EN 50343	Railway applications - Rolling stock - Rules for installation of cabling
EN 55011 A1	Industrial scientific and medical equipment — Radio-frequency disturbance characteristics Limits and methods of measurement
EN 55022	Information Technology Equipment - Radio Disturbance Characteristics - Limits and Methods of Measurement

Normative Standard	Description
EN 55022 (Class B)	Information Technology Equipment - Radio Disturbance Characteristics - Limits and Methods of Measurement
EN 60038	CENELEC standard voltages. Identical to IEC 60038:2009.
EN 60068-1	Environmental testing Part 1 General and guidance
EN 60076-1	Power transformers Part 1 General
EN 60146-1-1	Semiconductor converters
EN 60310	Traction transformers and inductors on board rolling stock
EN 60349-4	Electric traction Rotating electrical machines for rail and road vehicles Part 4: Permanent magnet synchronous electrical machines connected to an electronic converter
EN 60812	Analysis Techniques for System Reliability - Procedure for FMEA
EN 60947-1 A1	Low-voltage switchgear and control gear Part 1 General rules
EN 61000-4-2	Electromagnetic compatibility (EMC) Part 4-2 Testing and measurement techniques Electrostatic discharge immunity test
EN 61000-4-5	Electromagnetic compatibility (EMC) Part 4-5 Testing and measurement techniques Surge immunity test
EN 61000-4-8	Power frequency magnetic field immunity test
EN 61000-4-9	Electromagnetic compatibility (EMC) - Part 4: Testing and measurement techniques - Section 9: Pulse magnetic field immunity test - Basic EMC Publication
EN 61000-6-1	Electromagnetic compatibility (EMC) - Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments
EN 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards - Immunity for industrial environments
EN 61000-6-3	Electromagnetic compatibility (EMC) - Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
EN 61000-6-4	Electromagnetic compatibility (EMC) -- Part 6-4: Generic standards - Emission standard for industrial environments
EN 61025	Fault Tree Analysis

Normative Standard	Description
EN 61287-1	Power convertors installed on board rolling stock
EN 61373	Railway Applications – Rolling Stock Equipment – Shock and Vibration Test
EN 61375-1	Train communication network (TCN) Part 1: General architecture
EN 61375-2-1	Train communication network (TCN) Part 2-1 Wire Train Bus (WTB)
EN 61375-2-2	Train communication network (TCN) Part 2-2 Wire Train Bus conformance testing
EN 61375-3-1	Train communication network (TCN) Part 3-1 MVB
EN 61375-3-3	Train communication network (TCN) Part 3-3 CANopen
EN 61377-1	Railway applications – Rolling stock – Part 1: Combined testing of inverter – fed alternating current motors and their control system.
EN 61508:	EN version of UIC 61508 (& covered somewhat by EN 50128) Functional safety of electrical-electronic-programmable electronic safety-related systems
EN 62005-1	Reliability of fibre optic interconnecting devices and passive components
EN ISO 3095	Railway Applications - Acoustics - Measurement of Noise Emitted by Railbound Vehicles
EN ISO 3381	Railway Applications - Acoustics - Measurement of Noise Inside Railbound Vehicles
EN ISO 60204-1	Safety of Machinery – Electrical Equipment of Machines – General Requirements
IEC 60850	Railway Applications – Supply Voltages of Traction Systems
IEC 62128-1	Railway Applications-Fixed Installations-Part 1 Protective Provisions Relating to Electrical Safety and Earthing
IEEE 1483	Standard for Verification of Vital Functions in Processor-Based Systems Used in Rail Transit Control
IEEE 1653.2	Standard for Uncontrolled Traction Power Rectifiers for Substation Applications Up to 1500 V DC Nominal Output
IEEE 730	Standard for Software Quality Assurance Plans (ANSI)

Normative Standard	Description
IEEE 802.1d	Spanning Tree Protocol
IEEE 802.1p	Quality of Service in Ethernet
IEEE 802.1Q	VLAN in Ethernet
IEEE 802.1s	Multiple Spanning Tree Protocol (MSTP)
IEEE 802.1s/802.1Q	Multiple spanning Tree Protocol (MSTP)
IEEE 802.3	Ethernet TCP/IP
IEEE 802.3	Gigabit Ethernet Standard
IEEE 802.3ad	Link Aggregation Control Protocol
IEEE 802.3af	Power over Ethernet Standard
IEEE P1483	Draft standard for verification of safety for processor based systems used in rail transit control
IEEE Std	Standard for System and Software Verification and Validation
IEEE Std. 802.3	Ethernet TCP/IP
ISO 9001:1994	Quality System – Model for Quality Assurance in Design, Development, Production Installation and Servicing
ISO/IEC/IEEE 12207:	Information Technology - Software Life Cycle Processes
Montreal Protocol	Refrigerant R407C / R134a
NFPA 130	Fire Safety

Table 27-2 Informative international standards

Informational Standard	Description
CELEX 1300 (2014)	COMMISSION REGULATION (EU) No 1300/2014 on the technical specifications for interoperability relating to accessibility of the Union's rail system for persons with disabilities and persons with reduced mobility

Informational Standard	Description
EN ISO 15607	Specification and qualification of welding procedures for metallic materials — general rules
EN 50125	Railway applications - Environmental conditions for equipment
EN 50163	Railway applications, supply voltages of traction systems
EN 13749	Method of specifying the structural requirements of bogie frames
EN 10020	Definition and classification of grades of steel
EN 10027-1	Designation systems for steels - Part 1: Steel names
EN 10027-2	Designation systems for steels - Part 2: Steel numbers
EN 10088-1	Stainless steels - Part 1: List of stainless steels
EN 12258-1	Aluminium and aluminium alloys. Terms and definitions. General terms
EN 12663:	Structure Mechanics body/bogie connection only (6.7.2)
EN ISO 12100-1	Safety of Machinery – Basic Concepts, General Principles for Design – Part 1: Basic Terminology, Methodology
EN ISO 12100-2	Safety of Machinery – Basic Concepts, General Principles for Design – Part 2: Technical Principles
EN 15663	Vehicle reference masses
EN_60721-3-5	Classification of environmental conditions
IEC 1131	Programmable Logic Controllers – General Information
IEC 479-1	Effects of Current on Human Beings and Livestock
ISO 2768-1	Tolerances for linear and angular dimensions without individual tolerance indications
ISO_2631-4_AMD_1_2010-07	Mechanical vibration and shock -- Evaluation of human exposure to whole-body vibration
UMTA-MA-06-0153-85-8	Inductive interference in rapid transit signalling systems volume II: Suggested test procedures

Informational Standard	**Description**
FIB Bulletin 65 & Bulletin 66.	Model Code 2010
AASHTO 2017	AASHTO LRFD Bridge Design Specifications, 8th Edition with reference to ACI 318-14
ACI 318-14	Building Code Requirements for Structural Concrete and Commentary -
ASCE 21-13	Automated People Mover Standards
AISC 360-16	Specifications for Structural Steel Buildings, July 7th, 2016 Emergency Walkways and Miscellaneous steel structures shall be designed according to AISC 360-16 and referenced codes such as ASCE 7
ASCE 7-16	Minimum Design Loads and Associated Criteria for Buildings and Other Structures.

28 Appendix 2: Alignment Data

Monorail system alignment data following shall include drawings and tables describing the alignment of each track, including:

Mathematised alignment data

Chainages

Curve information including points.

29 Appendix 3: Guidelines for Rescue and Evacuation of Passengers

A project-specific risk analysis is required, which may lead to one or more of the following potential mitigations for either a vehicle and or infrastructure. This appendix is intended to indicate how these mitigations can be fulfilled where appropriate. Other mitigations might be appropriate to address identified risks.

Overview of potential mitigations resulting from the risk assessment but not limited:

I) Potential Mitigations for the Subsystem 'Vehicle'

No. 1: Emergency ventilation, at a standstill without external energy

No. 2: Emergency lighting, at standstill without external power

No. 3: Emergency communication, at a standstill without external power

No. 4: Emergency door function, designed for safe emergency opening

No. 5: Emergency aids

No. 6: Traction and braking availability

No. 7: Emergency power supply

No. 8: Hazard detection

II) Potential Mitigations for the Subsystem 'Infrastructure'

No. 9: Movement safety on the walkway (mechanical)

No. 10: Movement safety on the walkway (visual)

No. 11: Movement safety on the walkway (acoustic)

No. 12: Exit/transfer safety

No. 13: Position of walkways and rest areas

III) Potential Operational Mitigations

Note: These mitigations will be developed as part of the next revision.

Important Note

- Passenger evacuation can only be assessed from a system perspective and not only from either just the vehicle, wayside or other subsystems.
- Hazards can only be assessed from overall system perspective.

I. Potential Mitigations for the Subsystem 'Vehicle'

1. Safety Function – Emergency ventilation, at a standstill without external energy	
Statement	Ensure sufficient fresh air and tolerable temperatures during the person's stay
Hazard	If the vehicle stops on the track and remains there for too long, this may pose health risks and increased risks for certain passenger groups (e.g. children, older passengers, PRMs, etc.).
Normative Reference	1. IMA Specification: chapter 9.6.1.8 2. ASCE 21-13: chapter 7.7.2 with hint on 3.1.2.1 3. NFPA130, ISO19659-4: no requirement 4. TSI L&P: chapter 4.2.5.8 5. GB/T 50458: no requirement
Potential Mitigations (R1-X)	Quantitative and functional verification requirements: 1. Evaluation of air quality and temperature development using simulation, and 2. Testing the functionality of the switching functions from normal to emergency operation and the minimum operating time (in conjunction with the simultaneously active consumers) **R1-1)** A minimum ventilation time of 60 minutes*) must be ensured while guaranteeing an interior temperature <30°C and air quality <10000 ppm CO_2 with a vehicle occupancy rate of at least 75%. and **R1-2)** The function must be carried out safely (SRL2) if possible, electrically "on the hardware side", alternatively sufficient manually openable window areas (operation on instruction) can be realized.
Comments	The process organization for the incident/emergency concept can only guarantee the rescue of passengers with the exclusion of passengers with disabilities and reduced mobility by means of a fixed time period. Defining the value also enables a modular technical concept for energy supply and ventilation for vehicles. If shorter process sequences can be reached or if continued travel is guaranteed under all conditions (e.g. via battery traction), it is possible to deviate from the requirement by means of "proof of at least the same level of safety". *) If there is evidence available that the duration of the period of evacuation is less than 60 min, the emergency ventilation time must be then fully functional for the elaborated time of the evidence. Operator guidelines and national regulations must be considered in all project phases.

2. Safety Function – Emergency lighting, at a standstill without external power	
Statement	Ensure that the (safe) surroundings and the possible exit area on the vehicle are recognizable
Hazard	If you stop on the track and stay too long, there is a risk of claustrophobia and even panic reactions from passengers, when the vehicle is crowded, which is critical to health
Normative Reference	1. IMA-Specification: chapter 9.8.8.1 and 9.8.8.2 2. ASCE 21-13: chapter 7.11.2 with hint on 3.1.2.1 3. NFPA130: chapter 8.8.3 4. TSI L&P: chapter 4.2.10.4.1 5. EN13727-2: chapter 4.2.7 and 4.2.3 6. GB/T 50458: no requirement
Potential Mitigations (R2-X)	Measurement and functional verification requirements → Measuring the lighting situation in the entire room and in the door area → Testing the functionality of the emergency lighting switching functions and the minimum operating time (in conjunction with the simultaneously active loads) **R2-1)** The minimum illumination time must be more than 60 minutes*) while ensuring a luminous intensity of at least 5 lux in the entire vehicle interior and at least 40 lux in the door area. **R2-2)** The switchover function from normal lighting to emergency lighting must be implemented safely, if possible, electrically "on the hardware side" (SRL2). **R2-3)** A time-delayed lighting reduction from full to emergency lighting (energy-saving mode) is possible and it should be possible for staff to switch this manually in the vehicle.
Comments	The safety operation group responsible for the management of events/emergency can only guarantee the rescue of passengers in the event of unfavorable conditions by means of a fixed time period. Defining the value also enables a modular technical concept for energy supply and lighting for the vehicles. If shorter process sequences can be secured or if continued travel is guaranteed under all conditions (e.g. via battery traction), it is possible to deviate from the requirement by means of "proof of at least the same level of safety". The interior lighting can be used to illuminate the direct vehicle surroundings (e.g. use of side routes or aids for alighting and transferring). The front lighting of the vehicles is only suitable for illuminating an escape route to a very limited extent. **Note:** There is a wide variety of the requirements, as the 50 lux required in chapter 9.8.8.1 of the IMA specification, while the 10 lux required in chapter 8.8.3 of the NFPA in the door area, however the basis the EN requirement is 40 lux, the exact value shall be determined by the owner or according to the project specifications. *) If there is evidence available that the duration of the period of evacuation is less than 60 min, the minimum emergency lightning time must be then fully functional for the elaborated time of the evidence. Operator guidelines and national regulations must be considered in all project phases.

3. Safety Function – Emergency communication, at a standstill without external power	
Statement	Communication (via loudspeaker, SOS call, video) to the OCC must be reliably guaranteed in order to be able to recognize possible functional deviations and assistance requirements and to be able to give passenger instructions, this function must also be available in the event of a standstill without external power supply during the time passengers are in the vehicle
Hazard	In the absence of bidirectional active communication options and missing or ambiguous pictograms, there is a risk that passengers may act negligently and possibly unknowingly, resulting in panic reactions.
Normative Reference	1. IMA-Specification: chapter 9.13.9, 9.13.10, 9.13.11 and 9.18 2. ASCE 21-13: chapter 6.1.3, 6.1.6, NFPA 72-2002 (2002), 6.2 with hint on 3.1.2.1 3. NFPA130: chapter 8.9.2 4. TSI L&P: chapter 4.2.5.2, 4.2.5.3 and 4.2.5.4 5. EN 16334-2: 7.3 with hint on EN 62290 (concerns part 2, chapter 5.6.4) 6. EN 60268-16: 7. EN 16683: chapter 4.2 8. ISO 7010: table 3 and 4 9. GB/T 50458: chapter 4.3.6, 4.4.3, 18.8, 18.9
Potential Mitigations (R3-X)	Measurement and functional verification requirements → Measurement of the sound situation and camera angles in the entire cabin → Testing the functionality of the emergency communication switching functions and the minimum operating time (in conjunction with the simultaneously active loads) → Testing the system reactions in the event of conceivable defects being realized R3-1) Minimum operating time of communication, acoustically bidirectional and visually to the OCC, over 60 minutes*). R3-2) The triggering of a "call for help" (SOS) from a passenger to the staff (in the OCC or driver) must be permanently guaranteed (SRL4). These are usually installed in at least one door panel in the respective boarding area in conjunction with a microphone. For subsequent bidirectional audible communication and the independently functioning visual (camera) information channels shall be available to the OCC or the driver. R3-3) Autonomous instructions and voice announcements must always be clearly and undisturbedly audible in the passenger compartment at a level at least 3 dBA above the maximum possible interior noise level in the event of danger. R3-4) Comprehensible and permanently directly recognizable pictograms or pictorial handling/danger warnings must be installed.
Comments	A vehicle standstill combined with a delayed evacuation of passengers (e.g. over the minimum functional duration of 60 minutes for lighting, ventilation) leads to possible panic reactions in the absence of instructions. In the event of a fire, passengers must be given mandatory information on how to proceed to the next station or evacuation stop, together with any necessary instructions.

	*) If there is evidence available that the duration of the period of evacuation is less than 60 min, the minimum operating time of emergency communication must be then fully functional for the elaborated time of the evidence. Operator guidelines and national regulations must be considered in all project phases.

4. Safety Function – Emergency door function, designed for emergency opening	
Statement	The opening of vehicle doors (side and/or end wall) by passengers must be prevented while the train is moving and at a standstill if there is no safe exit or descent option for all groups of passengers, the opening of vehicle doors (side wall) for evacuation in the stations or at evacuation stops must be carried out centrally and side-selectively by the OCC in conjunction with the doors in the platform barrier. The opening of exit/descent openings (doors or floor hatches) to rescue passengers outside stations or evacuation stops requires technical and organizational measures, including assistance from passengers as instructed by the OCC and/or the rescue services. Self-rescue must be ensured by doors that require central authorization to open, so that independent opening into unsafe areas is prevented.
Hazard	The actions of passengers reacting in panic can then lead to subsequent critical hazards to people if there are unfavorable geometric boundary conditions when exiting and the subsequent movement with a lack of hazard recognition by the passengers (including those pushing behind).
Normative Reference	1. IMA-Specification: chapter 9.10.2.9, 9.10.2.10, 9.10.4 and 11.1.7 2. ASCE 21-13: chapter 7.8 with hint on 3.1.2.1 3. NFPA130: chapter 5.3.10 and 8.8.4 4. TSI L&P: chapter 5.2.5.5 5. EC 62290-2: chapter 5.6.4.3, 5.6.5 and 5.6.6 6. EN 14752: chapter 4.3.2, 4.3.3, 4.4, 4.7.2, 4.8, 5.1.5.1, 5.1.6.1, 5.5.1.2, 5.5.1.8, 5.5.1.3, 5.5.1.5, 5.5.3 7. EN 45545-4: chapter 4.3.2 und 4.3.3. with hint on EN 14752 8. EN 17168: chapter 4.1.7 and 4.1.13.6 (future in ISO 18298) 9. GB/T 50458: chapter 4.3.2 and 4.3.7
Potential Mitigations (R4-X)	Measurement and functional verification requirements → Testing the actuating forces of the emergency opening and possible auxiliary devices (exterior and interior) → Functionality of release processes for opening the passenger doors and other emergency exit components under defined boundary conditions → Real simulation of door opening tests to secure the prevention of opening <u>**R4-1)**</u> The opening of emergency exits by passengers shall be mechanically prevented in a safe manner, whereby a) opening by passengers only after release of the mechanical interlock by the OCC (this function must also be guaranteed in the event of fire) and b) opening via a second independent option using (e.g. central) mechanical auxiliary technology, which can be operated on instruction to the passenger, and functionally as mechanically and/or electrically safe as possible on the "hardware side" (SRL4). The actuating forces must comply with EN 14752. <u>**R4-2)**</u> Emergency door opening by external rescue services must always be mechanically guaranteed (SRL4). Accessibility can also be supported by on-board (if necessary, with the support of the passengers on instruction via the OCC) or mobile assistance technology (carried by the rescue services).

Comments	If passengers are able to open the doors immediately after a stop (sometimes regulatory functional release at speeds below 5 km/h), they may find themselves in a dangerous situation for self-rescue, falling due to geometrically unfavorable conditions between the vehicle "standing on the chassis beam" and the infrastructure, but also due to movement sequences on the walkway infrastructure. If there are no walkways next to the vehicles "standing on the chassis beam" (affects a large number of existing systems) or from the vehicle "hanging on the chassis beam", a downward rescue is not possible automatically and there would be a direct risk of falling. This also applies to walkways that cannot be used safely due to an excessive gap between vehicle and walkway, e.g. in curves or switch areas. If selective door opening is required (e.g. in the points area, opening is prevented by a gap that is too large) or if the walkway length at the station is limited (e.g. only the front door can be opened), this must be implemented in the control system starting from the OCC. This requires individual door control in the vehicle. Operator guidelines and national regulations must be considered in all project phases.

<table>
<tr><th colspan="2">5. Safety Function – Emergency aids</th></tr>
<tr><td>Statement</td><td>Depending on the specific circumstances
a) in the vehicle, taking into account operation in an emergency and
b) regarding the interface between the vehicle exit and the infrastructure (walkway on the route or in front of the station or at the evacuation stop) and
c) from the vehicle to the ground in the event of an irreversible stop between two stations aids may be required to ensure the safety of passengers in terms of whereabouts, movement and rescue (applies to all groups of passengers).
Possible national regulatory requirements may also have to be met if “proof of equal safety” is not granted by the accepting institution.</td></tr>
<tr><td>Hazard</td><td>If aids such as hand fire extinguishers or exit or descent aids are missing or do not function as intended, there may even be a considerable health risk. This can also lead to panic situations.</td></tr>
<tr><td>Normative Reference</td><td>1. IMA-Specification: no requirement
2. ASCE 21-13: chapter 7.2, 11.3
3. NFPA130: chapter 8.8.4
4. EN 45545-4: chapter 4.3.2, 4.3.3 with hint on EN 14752 and 6.3
5. EN 14752: chapter 4.11
6. GB/T 50458: chapter 4.3.2 and 4.3.3</td></tr>
<tr><td>Potential Mitigations
(R5-X)</td><td>Measurement and functional verification requirements
→ Testing the manageability and actuating forces of possible auxiliary equipment
→ Real simulation of evacuation procedures to verify the practicability of use
<u>R5-1)</u>
The portable fire extinguishers to be installed in the vehicle interior serve to ensure acceptable self-rescue conditions. Cooling extinguishing media (e.g. water with foaming agents) of categories A and B must therefore be used, unless national regulations prescribe other applications.
<u>R5-2)</u>
Based on the operator's defined emergency concept and the local conditions (e.g. no walkways on the track/floating track (Maglev track)) it must be possible to operate operating equipment [protection against vandalism] installed in the vehicle to ensure rapid rescue of passengers, which is not directly visible and accessible to passengers, in accordance with instructions.
It must be possible for external passengers (e.g. operating personnel, fire department) to set up the auxiliary equipment within 1 hour of the standstill (reference to the function time for lighting, ventilation, communication if there is no external power supply).
Any assistance that may be required must be instructed to the passenger(s) regarding handling via bidirectional communication. This concerns e.g.:
- assistance with opening the door and, if necessary, positioning a horizontal transition bridge to a train positioned (laterally or frontally) next to it,
- triggering a self-sufficient set-up function of any rescue equipment permanently installed in the vehicle,
- supporting the set-up of the rescue equipment from the ground to the vehicle and, if necessary, opening a hatch, for access to the passenger compartment by the rescue personnel.
The actuating forces must be complied with in accordance with EN 14752.</td></tr>
</table>

	R5-3) Based on the operator's emergency concept and the local conditions (e.g. geometric design of the side walkways), the exit aids must be designed for safe positioning and use for all groups of passengers. These can either be installed in the vehicle in the door area or kept securely in the room or also be supplied in a mobile form (e.g. deposited in the stations). These are handled by the operating personnel or the emergency services, who must also instruct and support the use of these by passengers.
Comments	Aids for the transportation of passengers with disabilities and reduced mobility (PRM) on the side walkways must be provided by the operator if the walkway cannot be used by the PRM. Operator guidelines and national regulations must be considered in all project phases.

6. Safety Function – Traction guaranteed	
Statement	Ensuring a minimum function of the vehicle traction, combined with a defined power reserve (how long / how far). The control system must ensure that the vehicle can continue to run or restart. If mechanical defects in the conductor rails cannot be ruled out, energy can be supplied via the traction battery as an alternative while ensuring the required residual charging capacity.
Hazard	In the event of a fire (e.g. due to technical defect or vandalism), it must be ensured that the vehicle can continue its journey. If the vehicle comes to a standstill as a result of a technical defect, malfunction or failure of the external power supply, this must not lead to a long stay in the vehicle, which could result in health-critical situations.
Normative Reference	1. IMA-Specification: chapter 9.7.1 2. ASCE 21-13: chapter 7.6 with hint on 3.1.2.1, 9.5 3. NFPA130: chapter 6.3.4 4. TSI L&P: chapter 4.1.4 with hint on EN 45545, 4.2.8.1.2 5. EN 45545-1 und -5: chapter 5 6. EN 50553: chapter 6.4 7. GB/T 50458: chapter 4.3.3
Potential Mitigations (R6-X)	Measurement and functional verification requirements → Testing of compensation including the absence of reaction of simulated defects to ensure the functionality of traction in the vehicle → Real simulation of journeys (performance verification for steady-state driving and associated with a restart) with limited traction available in the vehicle (targeted shutdown), verification of the limit value of the minimum storage energy in the case of battery-supported traction **R6-1)** Traction redundancy must be ensured in the vehicle via the separate drives, including their power supply. In addition to possible technical defects, this applies in particular to the effects of conceivable fire incidents. The basis for the assessment here is a fault case analysis by the vehicle manufacturer, possibly also in conjunction with control-side compensation from the OCC (switchovers). **R6-2)** The energy reserve to be permanently maintained in the batteries is to be determined depending on the traction, e.g. in conjunction with a start-up and possibly at a lower speed) over the longest section of the route and the steepest gradient between 2 stations, including the auxiliary power supply. At least 25% must be secured; if the value in a battery falls below this level, a decision must be made to abandon the vehicle. The energy reserve to be permanently maintained in the batteries (state of charge) must be determined depending on the traction requirement, including in conjunction with a restart and possibly at a lower speed over the longest section of the route and the steepest gradient between two stations, including the auxiliary power supply. At least 25% of the battery charging capacity must be guaranteed; if the value in a battery falls below this level, a decision must be made to stop the vehicle. **R6-3)** A technical fault of a battery or a traction unit must not have any effect on the other

	traction units, i.e. the absence of feedback must be ensured by the control system as far as possible electrically "on the hardware side" (SRL4).
Comments	There are two possible battery charging variants: a) exclusively in the station and possibly also combined with a start-up via the power supply of the conductor rail (e.g. installed before/after the station over a train length) to reduce the energy consumption from the traction battery b) keeping the state of charge constant via the continuous conductor rail (it should be noted that the fault scenario "mechanical defect of the conductor rail" cannot be compensated with this variant) - leads to immediate stopping due to greater mechanical impact, e.g., "towards the ground"). Operator guidelines and national regulations must be considered in all project phases. Any single point of failure shall not limit the vehicles to complete a trip to the next safe area.

7. Safety Function – Emergency power supply	
Statement	The vehicle battery (possibly also connected to the traction battery) must have sufficient capacity for the interior lighting, ventilation and passenger communication as well as the associated vehicle control during operation to guarantee the functions to be ensured in the event of a failure of the external power supply.
Hazard	If functions fail before the evacuation or rescue of passengers has been completed, → any operationally necessary procedures, e.g. in connection with instructions to the passengers in the vehicle, cannot be carried out safely → chaotic passenger reactions can arise, e.g. in the dark, in insufficient climatic room conditions, in a situation that can no longer be recognized by the OCC and can lead to independent and irrational actions by passengers.
Normative Reference	1. IMA-Specification: chapter 9.8.5 with hint on the analysis of 7.1.7 2. ASCE 21-13: chapter 7.12.2.3 with hint on 3.1.2.1, chapter 9.5 with hint on 3.1.2.1, chapter 5, chapter 6 3. NFPA130: chapter 12.4.4 4. TSI L&P: chapter 4.2.5.2., 4.2.5.8., 4.2.10.4.1. 5. EN: no requirement 6. IEC 62928: chapter 8.1 with hint on IEC 62619 7. GB/T 50458: no requirement
Potential Mitigations (R7-X)	Measurement and functional verification requirement → Testing the battery function based on the minimum capacity and loaded by all relevant consumers → Real simulation of safe shutdown processes in the event of a fault as well as failure detection and unavailability in the event of a capacity shortfall R7-1) The remaining capacity of the vehicle battery must ensure the necessary functions (lighting, ventilation, communication and control) for at least 1 hour*). R7-2) The energy supply function must be guaranteed as mechanically and/or electrically safe as possible on the "hardware side" (SRL4) and a shortfall below the lower capacity limit during operation must be detected in order to take the vehicle out of operation.
Comments	In the case of a traction battery operating in parallel, the necessary energy can be provided by this. *) If there is evidence available that the duration of the period of evacuation is less than 60 min, the remaining capacity of the vehicle battery must be then fully functional for the elaborated time of the evidence. Operator guidelines and national regulations must be considered in all project phases.

8. Safety Function – Hazard detection	
Statement	During operation, autonomous measures must be initiated immediately based on reliably detected deviations or events to ensure that the next station or an evacuation stopping point is reached. This applies to the associated sensors and the emergency call function (SOS).
Hazard	In the event of an undisclosed error, there is a risk of processes not running correctly to ensure personal safety, which may lead to an irreversible vehicle stop between two stations. As a result, rapid self-rescue or rescue by others may not be possible. Untrained processes in the OCC, such as manual switching from “normal operation” to “faulty operation” or “emergency operation” or situation-related actions, also harbor a risk potential, e.g. associated with a possible chain of errors.
Normative Reference	1. IMA-Specification: chapter 9.9.1 with hint on M5, 9.10.2.8, 9.18 with hint on 9.13.9 and 12.1, 9.20 2. ASCE 21-13: chapter 3.1.2.1, 7.6 (analysis acc. to 3.1.2.1) with hint on M5, 7.8, 7.10 with hint on NFPA 130, 7.10.2, 7.10.4, 9.5, 11.3 3. NFPA130: chapter 9.6.1.9 4. TSI L&P: chapter 4.2.1 5. EN 45545-1: chapter 5.2.1 with hint on M7 and M8 6. EN 45545-6: chapter 5.2 (table 1), 5.3, 5.4 (table 2 and 3) with hint on M1 / M2 / M3 / M10 / M4, 6.1, 6.2 and 7 7. GB/T 50458: chapter 4.3.3, 4.3.6, 20.2, 22 8. ARGE-RL: part 1, 2 and 3
Potential Mitigations (R8-X)	There is a measurement and functional verification requirement as part of the type test and commissioning/series test as well as the periodic inspections during maintenance with regard to fault disclosure. To ensure operational and personal safety, the functions, in particular those relating to - detection of a fire event on the vehicle, - a drop in tire pressure or a suspension system failure, - a battery fault, - a control system failure and - the passenger emergency call (SOS) be reliably monitored so that any necessary “switching reactions” can be initiated. If the function is no longer or only partially functional, a fault must be disclosed so that compensatory operational measures can be taken immediately, including those triggered or controlled by the OCC. Both the detection of a deviating state (operation no longer as intended) and the processes predefined for an impending critical event in accordance with the emergency concept and initiated autonomously by the technology must be displayed in the OCC so that - bidirectional communication with the passengers can be established and, if necessary, combined with situation-related instructions and - if necessary, manual intervention can be carried out using the dual control principle. The failure of components or functions that are necessary for the safe stay of passengers in connection with a possibly necessary evacuation or rescue of passengers must be revealed autonomously (by self-diagnosis) and/or by regular tests (during preventive maintenance). This applies, for example, to the emergency door function, passenger communication (loudspeaker, passenger emergency call, intercom system) and the switchovers to emergency lighting and emergency ventilation, but also to

switching off the ventilation (in the event of fire) and the electrical equipment affected by the fault/fire.

R8-1)

In the event of a fire, the safety of passengers in the vehicle must be guaranteed for at least 5 minutes – 4 minutes during the journey and 1 minute for self-rescue. This means that the fire alarm system in the passenger compartment must detect a defined fire event/measurement fire within 1 minute (reference to ARGE Guideline Part 1 on the "Vandalism ignition model", the time limit was determined based on real-life tests, so that it is still possible to remain in the vehicle for more than 4 minutes or to activate the necessary protective measures).

There is no SRL requirement that the construction materials be designed in accordance with the current normative requirements.

R8-2)

If the construction materials are not designed in accordance with the current normative requirements or if there is no self-rescue option into an adjacent passenger compartment via the carriage gangway, the fire alarm system (FAS) installed in the compartment and qualified in accordance with B-1) and the fire suppression system (FSS) must meet the SRL2 requirement. The FSS in the passenger compartment must be qualified on the basis of a defined fire incident/designated fire (reference to ARGE Guideline Part 2 on the "Vandalism ignition model") for the period until the self-rescue or third-party rescue is completed (at least 5 minutes, see *).

R8-3)

Electrical installations with a fire risk potential (voltage level e.g. over 12A at 110V, 5A at 400V, 2A at 700V) must be equipped with a fire alarm system and, in the case of a fire risk potential (voltage level e.g. 16A at 110V, 10A at 400V, 5A at 700V), also with a fire extinguishing system (FES) (reference to ARGE Guideline Parts 1 and 2, see *).

Traction motors and traction battery systems must be thermally and electrically monitored and a failure has to be detected, which must lead to a safe electrical shutdown with SRL4 if the limit value is exceeded.

R8-4)

In order to ensure continued travel to the next station or an evacuation stop, proof of the emergency run flat function must be provided with complete loss of tire pressure at least 30 km/h (at least 5 minutes at 75% load condition, see *) time to go to next station (not 5 minutes) and further on to the next maintenance facility.

R8-5)

If a part of the traction system fails (concerns magnetically lifted and driven vehicles), continued movement must be ensured by using the skids at reduced speed (at 75% load, see *).

R8-6)

A traction redundancy of at least 50% must be ensured, combined with proven freedom from retroactive effects (prevention or at least limitation of consequential faults) based on conceivable technical failures or malfunctions of the control system and power supply. Any single failure should still operate the system regardless of the percentage of redundancy. (without loss of performance; for safety with limited performance)

R8-7)

If a traction battery system is used, monitoring and control must be carried out via a safe battery management system (BMS) due to the spatially concentrated energy supply. This concerns the following functions in particular:

- the battery cells must be safely monitored with SRL2 in relation to an excess temperature (battery cell or smallest pack) in order to prevent thermal runaway

	- overcharging and deep discharging of battery cells or ultra-caps (risk of bursting/bursting) must be prevented electrically with SRL4 - the introduction of overvoltage or undervoltage must be prevented by measurement and the cell voltage must be monitored - In the event of danger, it must be possible to safely switch off the battery system externally (on the vehicle side) or individual modules internally (on the system side) electrically with SRL4 (emergency stop) - the software architecture of the FDAS – Fire Detection and Alarm System must be divided into a safe and reliable part so that the safety verification can be carried out in a structured manner in relation to defined parameters and functions
Comments	*: Depending on the maximum distance between 2 stations (or to the next evacuation stopping point) and the operating speed as well as the passenger compartment volume, the installation and the required SRL classification of the fire protection technology (such as FDAS - Fire Detection and Alarm System, FSS - Fire Suppression System, FES - Fire Extinguishing System) is determined on the basis of the fire impact analysis (criticality of the fault sequence). Operator guidelines and national regulations must be considered in all project phases.

II. Potential Mitigations for the Subsystem 'Infrastructure'

If walkways for emergency evacuation are realized, the following requirements must be met.

9. Safety Function – Safe movement along the walkway (physical)	
Statement	Use is associated with risks if the design is inadequate (in terms of dimensions, surface, gap, lighting, staircase)
Hazard	If required, aids for passengers with disabilities and reduced mobility must be specified in accordance with the defined operational measures, depending on the dimension of the infrastructure that can be used for the movement of passengers. This must be specified in the incident and emergency procedure, e.g. storage location, transportation for use and use by whom.
Normative Reference	1. IMA-Specification: chapter 17.6 2. ASCE 21-13: chapter 11.3.3, 11.9, 7.7.6.3 3. NFPA130 (2020): chapter 6.3.1, 6.3.2, 6.3.3, 6.3.3.5, 6.3.3.6, 6.3.3.7, 6.3.3.8, 6.3.3.9, 6.3.3.10, chapter 7 of NFPA 101 4. GB/T50458: chapter 2.0.19, 2.0.20 5. ASCE 7: chapter 4.4.2 6. EN 1991-1-1: chapter 6.4 7. EN 1991-2: chapter 5.3.2.1 8. DIN 18040-3: chapter 4.2, 4.3, 4.4 9. DIN 18065: chapter 6.10, 6.1.3, 6.3, 4.4 10. TSI PRM 2014/1300: chapter 4.2.1.4 9. TSI SRT 1303/2014: chapter 4.2.1.6
Potential Mitigations (R9-X)	Measurement and functional verification requirement with respect to → the dimension situation (gap, height, width, depth) → Movement options and safety aids for transporting PRM on the walkway → Test for handling safety of aids <u>R9-1</u> **Structural requirements** The following characteristic loads must be applied as a minimum when dimensioning the emergency walkway (horizontal surface) and stairs: - Dead weight - Live loads of at least 5 kN/m² arranged over the entire surface - Dynamic, vibrating and impact forces (e.g. wind and earthquake loads) If a handrail or similar system is installed, a horizontal load on the railing of 1 kN/m at the height of the railing must be applied throughout. It is essential that all relevant loads are fully considered in the design of beams and connections. This comprehensive approach involves not only identifying the different types of loads to which the structure is subjected but also understanding how the loads interact with each other. In addition, it is important to apply the correct combinations of static load cases during the design process. These combinations contribute significantly to the structure's ability to withstand the applied forces while ensuring safety and stability. <u>R9-2</u> **Dimensional requirements** An emergency walkway is recommended to have a continuous minimum width of 80 cm. If obstacles are placed adjacent to the emergency walkway, they may narrow the emergency walkway to 70 cm for a maximum length of 2 m.

	The opening of the gap between 2 grid panels / slabs shall be < 2 cm in the transverse direction, < 1.5 cm in the longitudinal direction and in height (unevenness) < 0,5 cm. Furthermore, there shall be no height offset respectively no stumbling hazard that exceeds 2 cm height from the walking level. The maximum transverse slope of an emergency walkway with a closed surface must not exceed 2.5 % and sufficient drainage must be ensured. A gradient (which should match the maximum rolling stock gradient) in order to avoid trips and falls during a fire evacuation. (1 in 16,67; equal to 6 %, ISO 21542:2021, chapter 8.2). Stairs must be designed using the stair formula: 2x height + depth = 590 - 650 mm. The following geometry of the steps of stairs must be observed´ - Height (rise) between 140 and 190 mm - Step length between 260 and 370 mm - Usable step width at least (1000 mm) **Fall protection** From a fall height greater of 76 cm, fall protection (barrier, handrail) of at least 90 cm height must be installed continuously. From a fall height of > 12 m, the height of the fall protection must be at least 110 cm. A handrail at a height of 90 - 110 cm with a diameter of 2.5 - 6 cm must be arranged continuously. At the beginning and end of the handrail it must angled downward in a range of 30-40° for a length of 10 cm. In order to prevent slipping under the upper railing/handrail bar, longitudinal or transverse interlocks (e.g. struts, ropes, mesh, glas) must be provided, spaced max. 15 cm apart. **R9-3 Slip resistance** All surfaces of the emergency walkway and stairs must have a minimum SRT value > 55 or an R-value of R11. *Note: SRT = Skid Resistance Tester acc. DIN 18040-3* *R = Slip resistance class (R11 = increased slip resistance) acc. DIN 18040-3*
Comments	Higher national legal minimum requirements must be followed. Operator guidelines and national regulations must be considered in all project phases.

10. Safety Function – Safe movement along the walkway (visual)	
Statement	The recognizability of movement areas (walkways, boundaries, stairs, step gaps) must be ensured by suitable visual, tactile or high-contrast features.
Hazard	Missing or poorly recognizable movement areas can lead to tripping, slipping and falling accidents. In emergencies, passengers may fall due to escape routes that are not clearly marked, or there may be subjective insecurities that lead to a delay in movement and thus to congestion. This can lead to panic and pushing with falls.
Normative Reference	1. IMA-Specification: chapter 17.6 2. ASCE 21-13: chapter 11.6 3. NFPA130 (2020): chapter 6.3.3, 6.3.3.1 - .4, 6.3.5.9, 6.3.5.13, NFPA 70, 6.3.5.14 4. ISO 7010: table 3 and 4 5. GB/T 50458: chapter 20.6.4 6. TSI SRT 1303/2014: chapter 5.2.1.5.5
Potential Mitigations (R10-X)	Measurement and functional verification requirements regarding → the visual situation (luminosity, uniformity of lighting, absence of glare) <u>R10-1</u> **Visual requirement for walkway surface** Surfaces of the emergency walkway shall comply with a luminance of max. 5000 cd/m², unless they are designed as grids (to prevent glare). <u>R10-2</u> **Requirement for emergency exit signs** These are required in areas where an area "planned" for evacuation is approached (e.g. upstream or downstream of the station, evacuation holding areas between 2 stations). Emergency exit signs with direction indicators must be installed at a maximum distance of 50 m from the respective emergency exit. <u>R10-3</u> **Emergency lighting requirement** The entire emergency walkway must have a continuous illuminance of 2.7 lux. This can be provided by artificial lighting or by adjacent light sources (e.g. streetlamps, highways, city districts, etc.). Measured along the emergency exit path at the walking surface. If emergency lighting is only switched-on during evacuation, it must be fully functional for at least 1 hour.*) Emergency lighting and emergency exit signs must be separately wired and centrally powered from the emergency power distribution panels. Although 2.7 lux is required, the preferred value is 5 lux (reference to vehicle requirements) and at least 40 lux in level changes (e.g. stairs)
Comments	National legal minimum requirements that deviate from the requirements of ISO 7010 must be followed. The reference for: <u>Europe exit signs:</u> The requirements of Directive 92/58/EEC of June 24, 1992 and Annex A, point 1 apply. <u>America exit signs:</u> The requirements of NFPA 70 regarding emergency exit signs apply and important signs must be integrated into the emergency lighting system. *) If there is evidence available that the duration of the period of evacuation is less than 60 min, the emergency lighting must be then fully functional for the elaborated time of the evidence. Operator guidelines and national regulations must be followed in all project phases.

11. Safety Function – Safe movement along the walkway (acoustic)	
Statement	Acoustic support must be verified by a speech intelligibility test, if acoustic support (dedicated places) is available
Hazard	A lack of acoustic support can lead to panic, confusion and delays and thus to increased danger for the passengers being evacuated.
Normative Reference	1. EN 16683 2. DIN EN 50849: chapter 5.1 3. TSI PRM 2014/1300: chapter 4.2.1.11 4. EN 60268-16:2011: table I.1
Potential Mitigations (R11-X)	Measurement and functional verification requirements regarding → the acoustic situation (volume, intelligibility taking into account the specific ambient noise) **R11-1 Installation requirement** In areas with horizontal changes, such as stairs and potentially longer narrowing, as well as transitions or path convergences with changes in direction, cameras connected to loudspeakers for the control center must be installed so that instructions can be given to people walking through these areas. Alternatively, this can also be achieved by people on site using mobile technology. **R11-2 Noticeability** The Speech Transmission Index for Public Address (STI-PA) value of spoken information must be at least 0.55 in the entire section of the emergency walkway. Proof can be provided in accordance with national regulations (e.g. EN 60268-16). Regular tests and measurements for volume constancy must be carried out.
Comments	The intelligibility of the announcements is ensured directly on the vehicle via its loudspeaker system with the doors open. Operator guidelines and national regulations must be considered in all project phases.

12. Safety Function – Exit/transfer safety	
Statement	The safety of disembarking and transferring refers to passengers being able to get out of the vehicle safely, quickly and in a controlled manner and reach the evacuation platform.
Hazard	Errors or deficiencies in the safety training of the staff for disembarking and transferring passengers can result in serious injuries or even life-threatening consequences for the passengers.
Normative Reference	1. IMA-Specification: chapter 17.6 2. ASCE 21-13: chapter 11.8.1 3. NFPA130: no requirement 4. GB/T 50458: chapter 5.3.8
Potential Mitigations (R12-X)	Measurement and functional verification requirement with regard to → the dimensional situation and combination when exiting in relation to the gap and the step-off height with regard to the transition from the vehicle to the walkway <u>R12-1</u> **Horizontal gap dimension** The horizontal gap between the vehicle and the walkway shall be at least 50 mm*) at any point along the route (even in tight bends) when the vehicle is in the station or at a rescue area. The horizontal gap between the vehicle and the walkway is recommended not to exceed 250 mm*) at any point along the route (even in tight bends) (assessed when the vehicle is stationary). The horizontal gap must be designed in such a way that a safe transition from the vehicle to the walkway is possible. Therefore the 250 mm is recommended. If the gap is greater, operational equipment e.g. folding evacuation bridges or ramps should be available. It is assumed that younger passengers and PRM are assisted by fellow passengers when getting out of the vehicle. <u>R12-2</u> **Vertical offset height dimension** The surface of the walkway is recommended to be level with the vehicle and not to exceed a maximum of 250 mm below the threshold of the vehicle. If this height offset is greater, access and exit aids should be provided and at least one door should be equipped with aids for the transportation of passengers with disabilities and reduced mobility. It is assumed that younger passengers and PRM are assisted by fellow passengers when alighting. *(could be outside the vehicle, should be available)*
Comments	National legal minimum requirements must be followed. Operator guidelines and national regulations must be followed in all project phases.

Introduction to 'Safety Function – Position of walkways or rescue areas':
When assessing the requirements for the placement of emergency egress routes to enable passenger evacuations all operational scenarios shall be considered and analyzed, including degraded modes, to establish the possible locations where a train could be stopped or immobilized.

13. Safety Function – Position of walkways or rescue areas	
Statement	It must be possible for passengers to rescue themselves quickly and completely if a fire develops inside the vehicle. There must be a safe exit for passengers in the event of operational constraints, where passengers can move safely from a vehicle parked in front of the station into the station without restrictions (e.g. if station is occupied by another vehicle).
Hazard	In the event of a fire in the vehicle during the journey, there are considerable health risks or even fatalities if you stay in the vehicle too long and rescue yourself from the danger zone. In the event of a disorganized exit from the vehicle, e.g. in direct view of the station and walkways, there is a risk of injuries and panic reactions as a result of the perception of accidents.
Normative Reference	-
Potential Mitigations **(R13-X)**	Document review for the "Evacuation report strategy", based on the planned operating concept (more detailed if necessary) There is a requirement for measurement and functional verification regarding → the dimensional situation for exiting, with a platform elevated next to the vehicle floor, including the accumulation of passengers on it → the lighting / acoustic support / situation recognition → the PRM support for reaching the floor <u>R13-1</u> **Position requirement** Arrangement of a walkway, if not implemented or feasible on the track: 1. at least a section to reach each first door of each vehicle (smallest unit with intercar gangway) before and after the station <u>Note:</u> - the switch area should be located before/after the defined rescue area - if safe vehicle evacuation is only operationally possible via the front vehicle doors, the area can be shortened (in the sense of a short platform extension). 2. If the travel time is too long or the station distance is too long, an evacuation stopping point should be provided if no qualified fire-fighting equipment is installed in the vehicle to compensate for this. <u>R13-2</u> **Space requirements on the walkway / platform** The requirements for the gap dimension, horizontal level crossing and independent wheelchair movement are comparable to those for the platform situation. The width of the walkway or the space required on the platform (separate evacuation stops on the route) next to the vehicle is determined by the maximum possible number of passengers in the vehicle plus 25%. This ensures that - the train is fully cleared. - there is sufficient space for wheelchairs.

	- passengers can keep away from the vehicle affected by the fire (smoke/flames escaping through open doors). Note: The structural requirements listed above (refer to R9-2, R12-1, R12-2 must be ensured. **R13-3 Support requirement** Since there is an independent self-rescue from the vehicle, there must be immediate lighting and sound and situation recognition via cameras (activated by the OCC). The functional requirements are defined with SRL2, as there is a lighting and sound system starting from the vehicle and sufficient space is secured on the "platform", but panic situations must be prevented, and instructions must be available. Note: The specific requirements for lighting and public address have already been outlined above. In the case of an evacuation stop, assistance for PRMs in descending to the ground must be operationally guaranteed, combined with the possibility of assistance by the passengers themselves or by approaching personnel.
Comments	It should be noted that existing monorail systems either have no walkways next to the track or, due to national regulations, have walkways along the entire length of the track. If walkways are installed along the entire length of the track, the requirements for dimensional design and the use of aids apply in particular. The door control system must prevent passengers from exiting independently if assistance is required. Operator guidelines and national regulations must be considered in all project phases. The stations represent a secure area for rescue operations.

III. Potential Operational Mitigations

Note: Operational mitigations will be developed as part of the next revision.

xx	**Focus**	**Operational constraints in the event of extreme environmental impacts**
		t.b.d.
xx	**Focus**	**Restarting after the vehicle has stopped on the track**
		t.b.d.
xx	**Focus**	**Requirements for an emergency concept**
		t.b.d.
xx	**Focus**	**tbd.**
		t.b.d.

International Monorail Association

Performance Specification for a Turnkey Mass Transit Monorail System

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